MARCH 1953

Chemical Engineering Progress

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Chemical Engineering Progress

Volume 49

Number 3

MARCH

1953

Editor: *F. J. Van Antwerpen*

OPINION AND COMMENT Page

BASIC RESEARCH IS A PROBLEM 111

ENGINEERING SECTION

FLUIDIZED-SOLIDS TECHNIQUE IN THE PETROLEUM INDUSTRY
R. C. Gunness 113

ABSORPTION OF HYDROGEN FLUORIDE
Nathan Gilbert, I. A. Hobbs, and W. D. Sandberg 120

BUBBLE-PLATE EFFICIENCIES IN ETHANOL-WATER FRACTIONATION
G. D. Shilling, G. H. Beyer, and C. C. Watson 128

MASS TRANSFER FROM BENZOIC ACID GRANULES
G. C. Evans and C. F. Gerald 135

MASS TRANSFER IN A FLUIDIZED BED
J. C. Chu, James Kalil, and W. A. Wetteroth 141

RATE PROCESSES IN CHEMICAL REACTORS
R. H. Wilhelm 150

WE TALK TO OURSELVES—TOO MUCH
D. H. Killeffer 155

PLASTICS CEMENT REFERENCE SHEET
R. B. Seymour and R. H. Steiner 158

NEWS

	Page		Page
TORONTO	17	A.I.Ch.E. CANDIDATES	42
TECHNICAL PROGRAM	20	LOCAL SECTION	54
INDUSTRIAL NEWS	22	FUTURE MEETINGS	60
MARGINAL NOTES	28	NEWS ABOUT PEOPLE	61
DATA SERVICE	35-38	CLASSIFIED	66
SECRETARY'S REPORT	40	NECROLOGY	68

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, one year $6.00; two years $10.00 (Applies to U. S. and possessions only.) Canada $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under Act of August 24, 1912.

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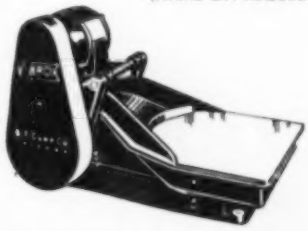

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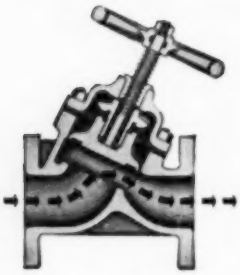

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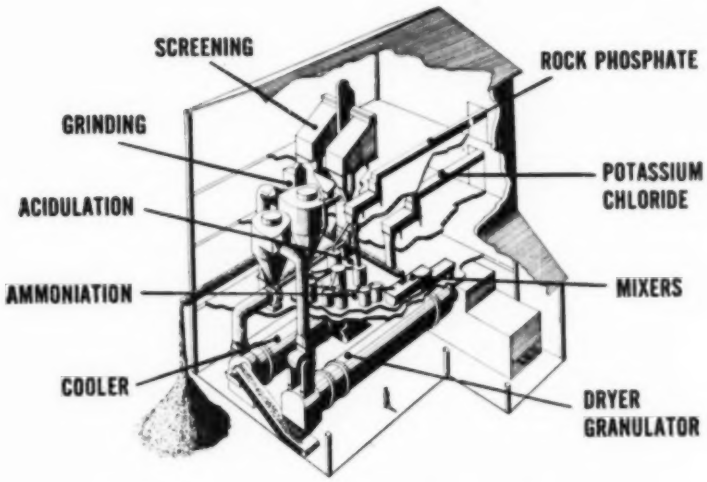

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10	10	17	(sulfo-nitric acidulation)
11	11	11	" " "
10	15	20	(phospho-nitric acidulation)
12	15	18	" " "
12	12	20	" " "
14	14	14	" " "
10	20	20	" " "

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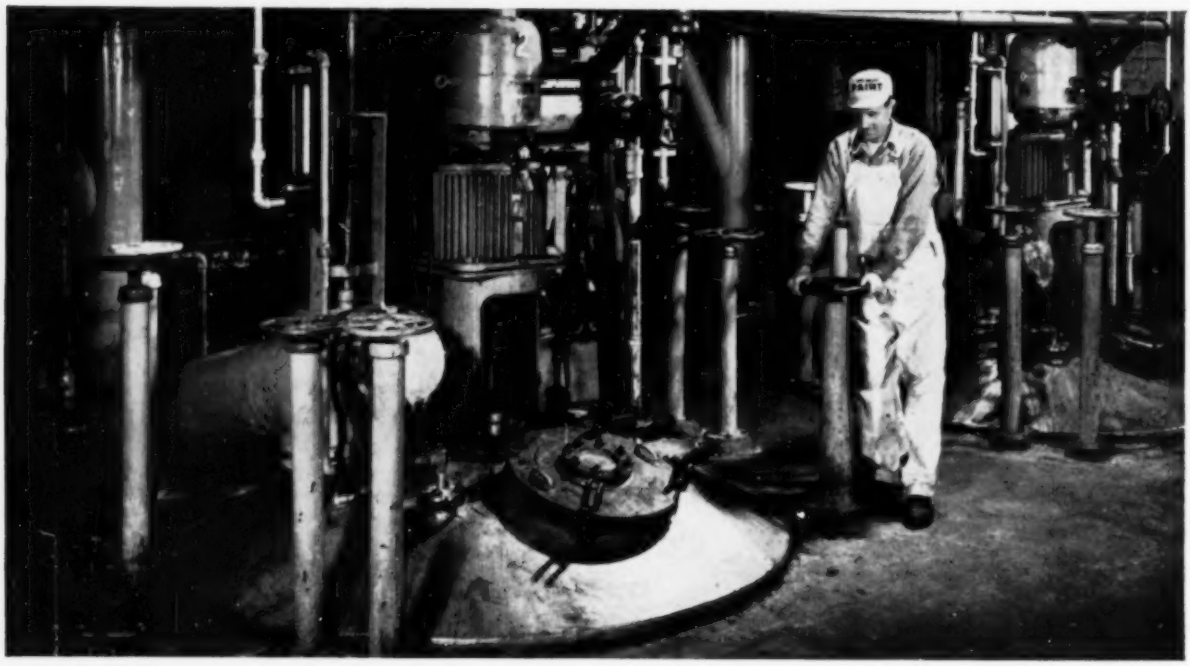

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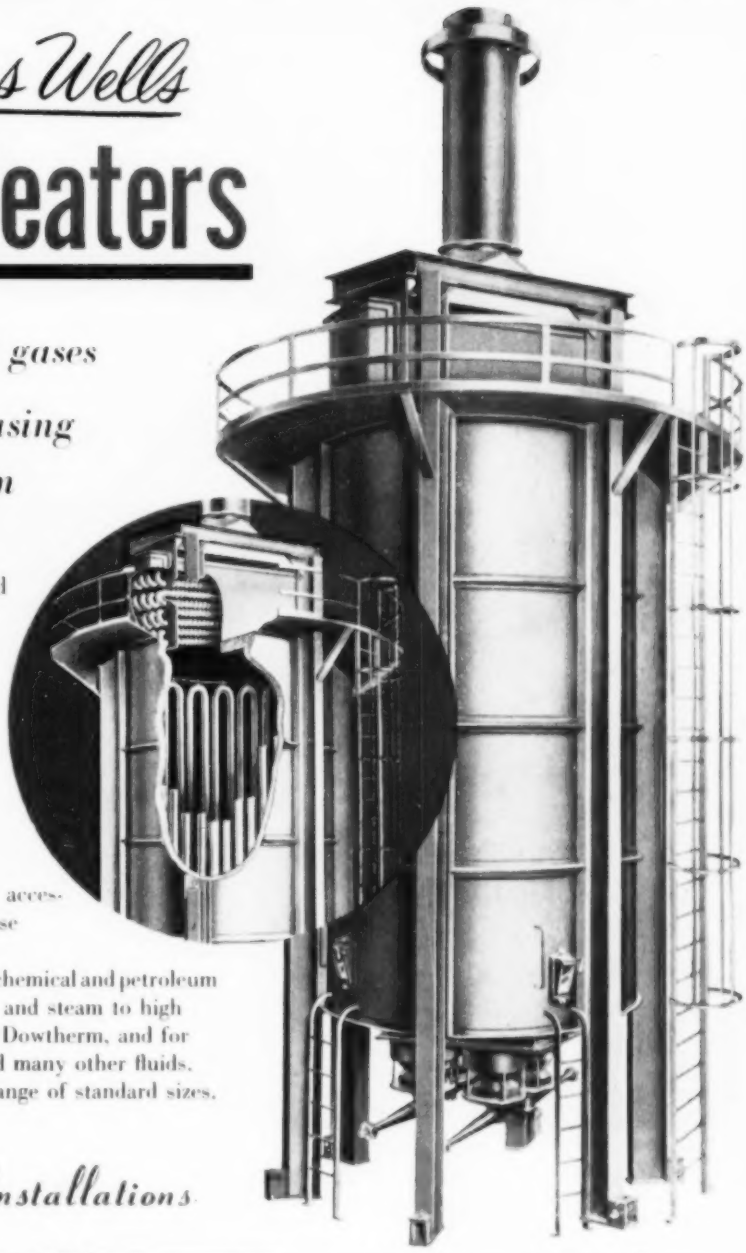

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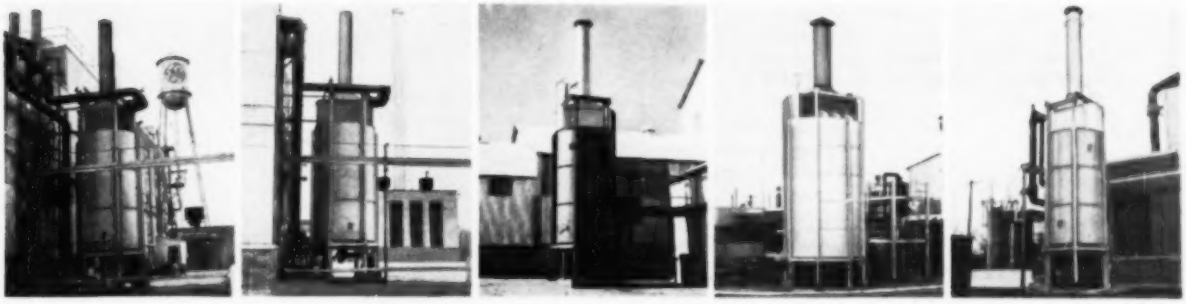

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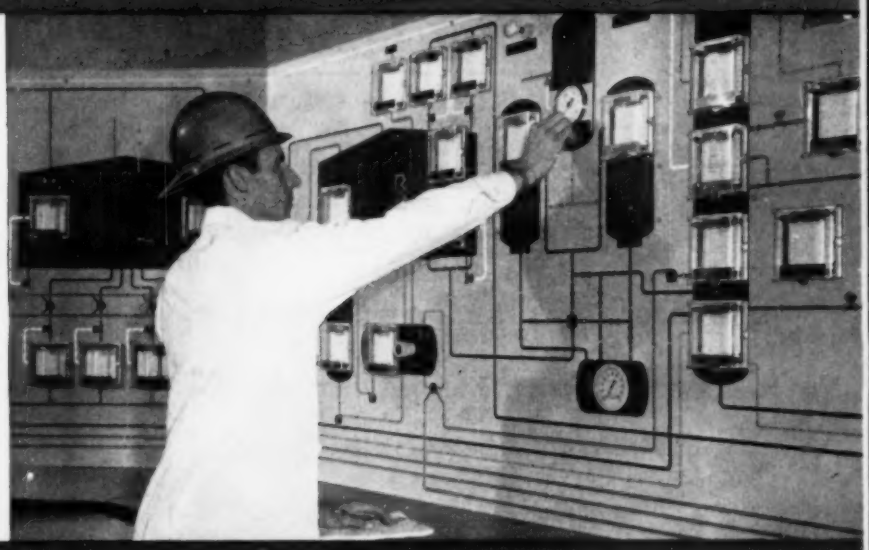

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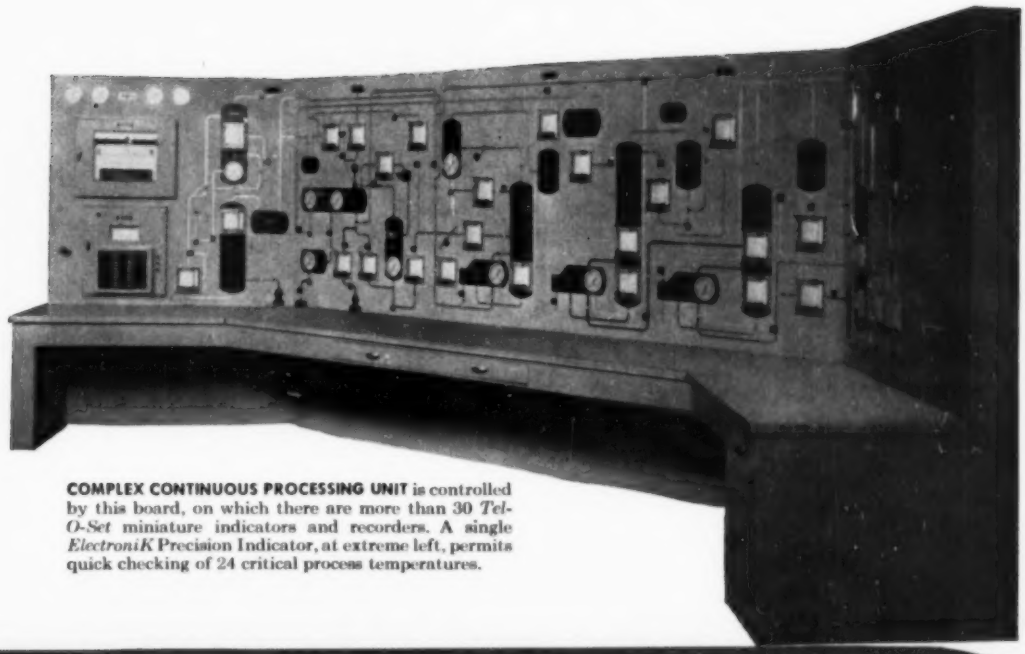

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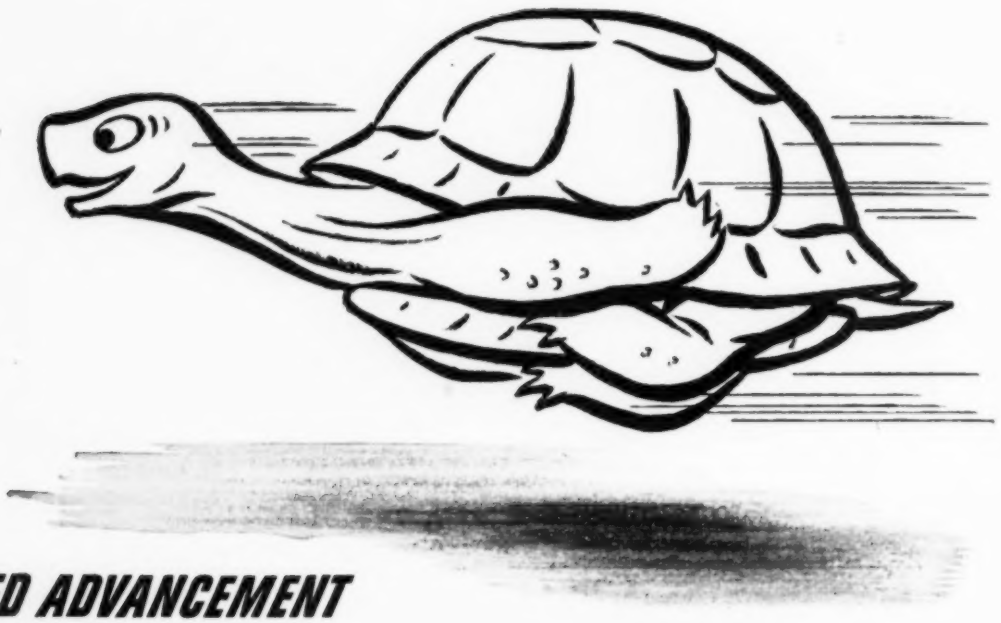

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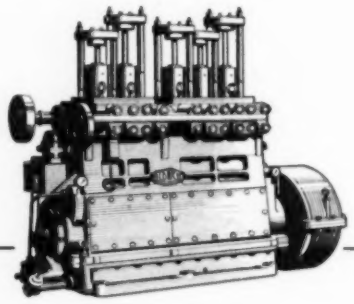

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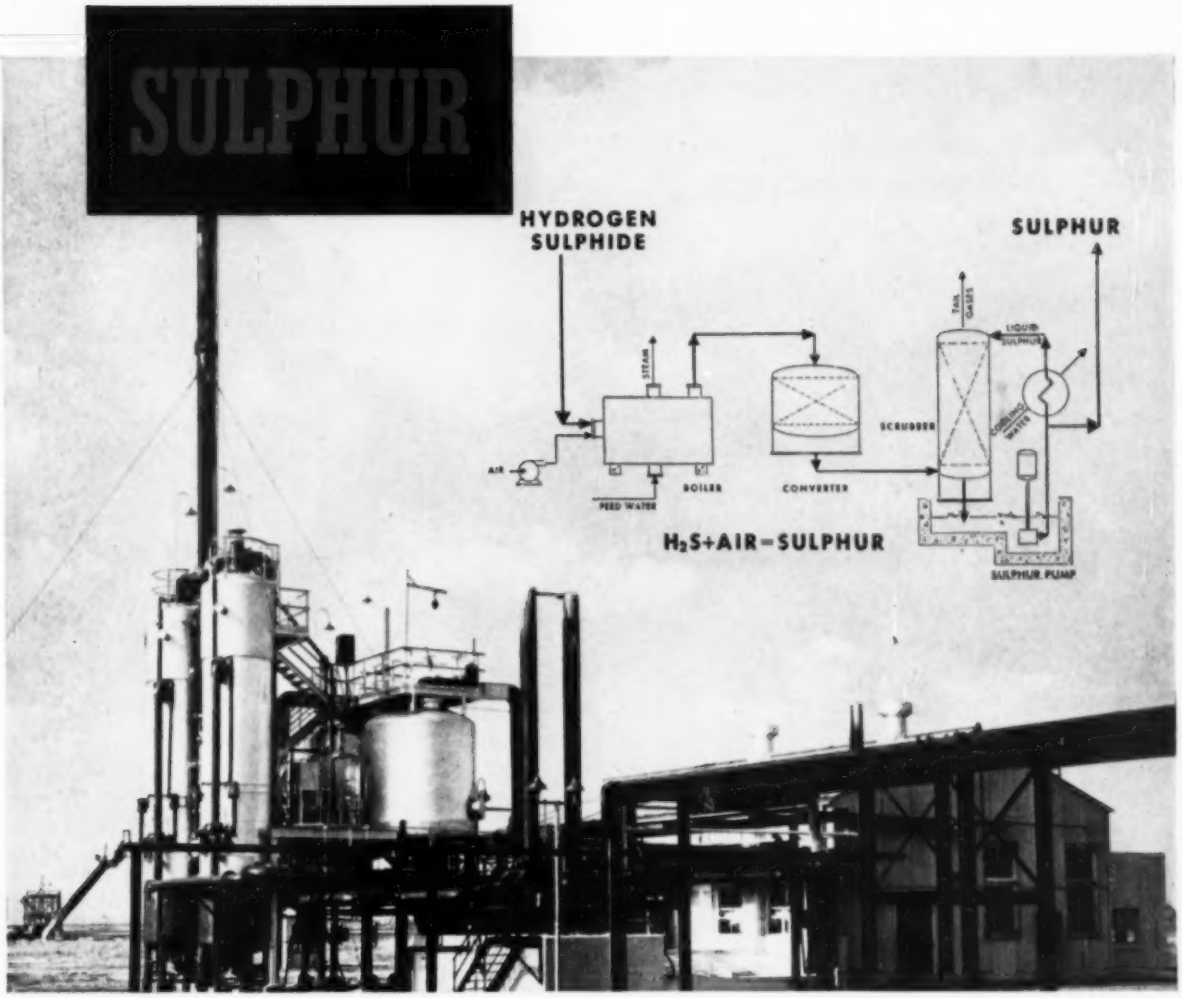

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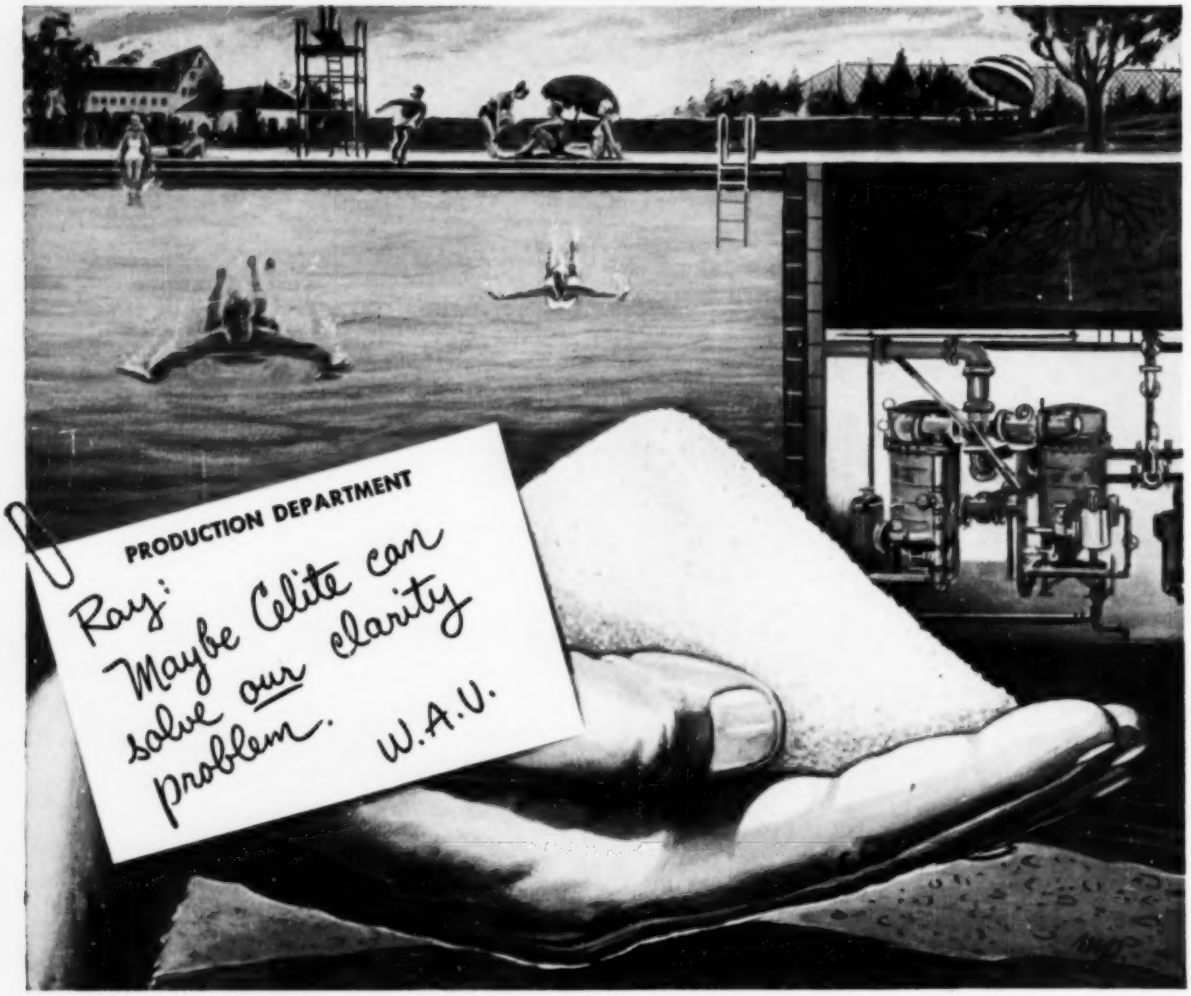

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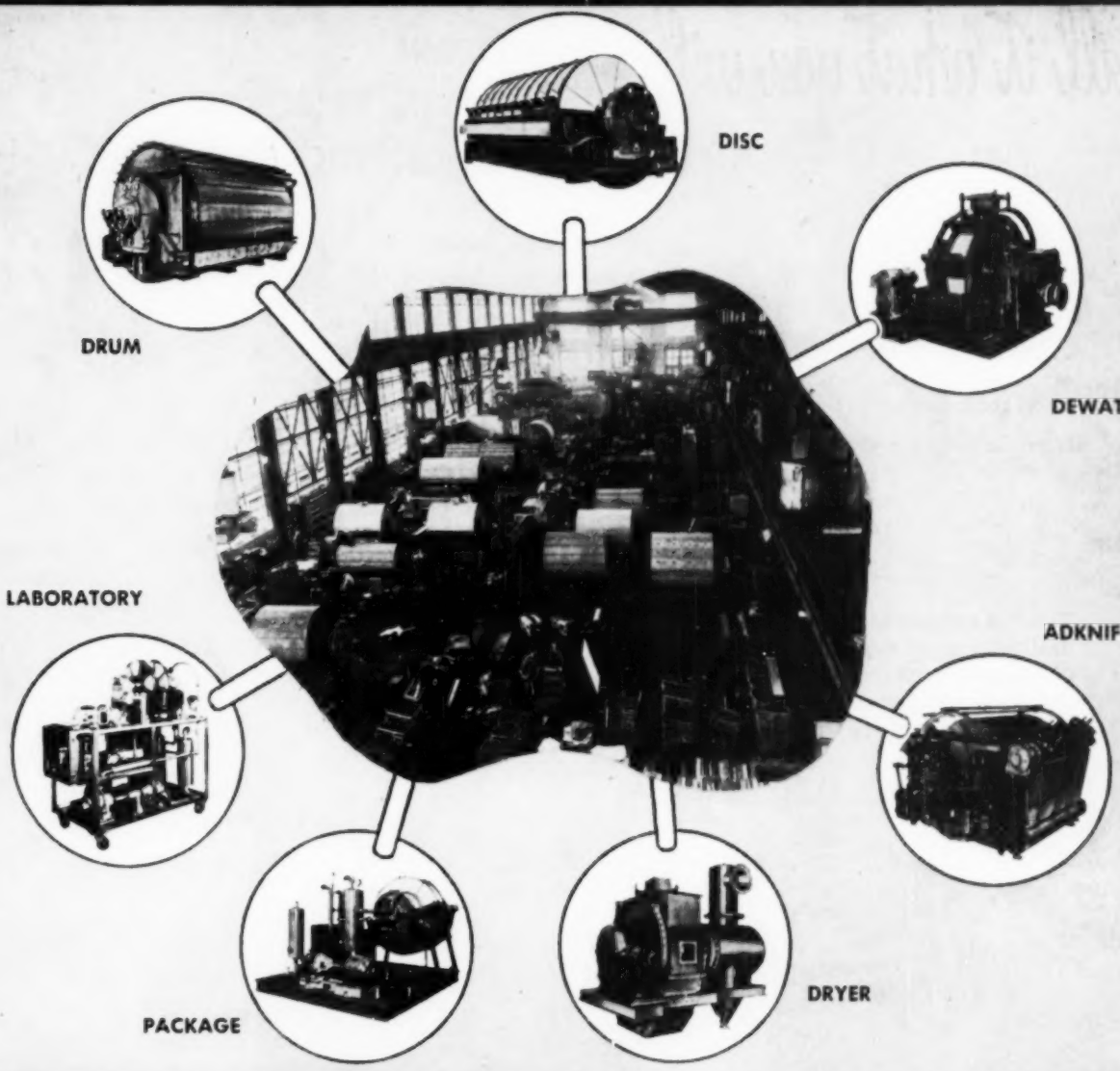

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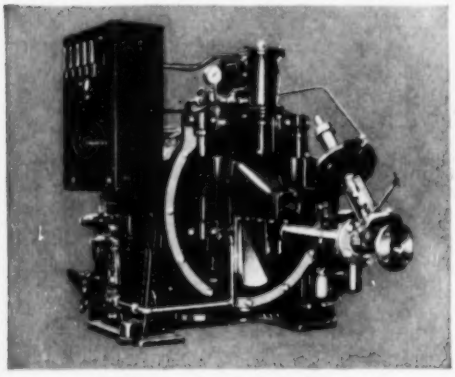

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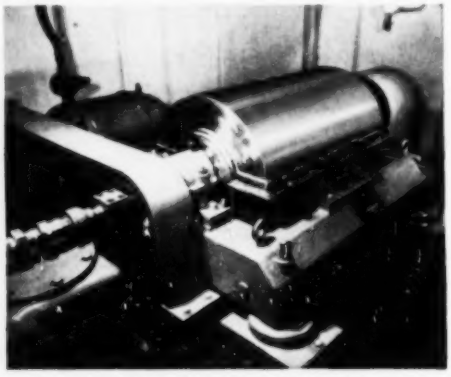

The Sharples Super-D-Canter

A horizontal, solid bowl centrifuge for continuous separation of solids from liquids—especially for slurries and sludges containing relatively large amounts of solids of varying size. Two types are available, for crystalline and amorphous solids.

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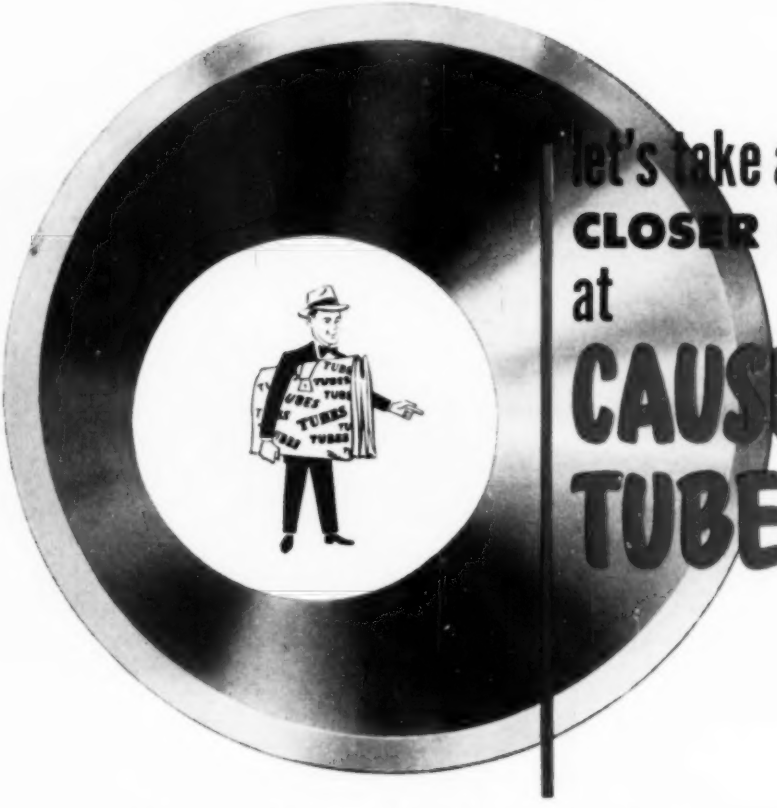

let's take a CLOSER LOOK at CAUSES OF TUBE FAILURES

Tubes are critical materials. Peak production of petroleum products is vital to the defense program. These are two urgent reasons for giving extraordinary attention *now* to getting optimum failure-free service from tube installations in petro-chemical facilities.

Of major importance in securing best operating results is an understanding of the numerous factors affecting tube life in high pressure, high temperature applications. Innumerable investigations of tube failures in such service over a 25-year period show that they are most frequently caused by circumstances other than actual physical defects in the tubes themselves. By far the most common causes of failures are overheating, excessive pressures, corrosion, and scaling due to tubes being subjected to improper operating conditions.

Enumerated are some of the more prevalent reasons, based on extensive studies, that account for excessive tube temperatures and attendant failures in chemical and petroleum conversion equipment. These are presented in the hope they will aid engineers and operating personnel to get better-than-ever service from their tube installations.

Through Mr. Tubes—your local B&W Tube Representative—is available a wealth of data on the behavior of tubing steels under conditions embraced in modern processing plants. It may pay you as it has so many others to call on this vast source of useful information.

Some Common Causes of Reduced Tube Life and Increased Maintenance

1. Excessive transfer rates in furnace equipment.
2. Coking of tubes — either expected or extraordinary.
3. Failure to clean tubes at regularly scheduled periods.
4. Unexpected radiation from bridge wall or refractory surfaces.
5. Improperly calibrated fuel meters on burner equipment.
6. Increase of product temperature over a safe design limit.
7. Unequal heating around circumference or along tube length.
8. Excessive furnace temperatures.
9. Guessing at tube metal temperatures.
10. Increase of pump pressure of maintain through-put.
11. Abuse during mechanical decoking, or scaling during burningout operations.
12. Improper supports resulting in bending or sagging.
13. Lack of control of furnace atmosphere to retard scaling.
14. Corrosion of ends or body of tube or both.
15. Carburization and exfoliation of carburized layer.
16. Abrasion or erosion due to coke in fluid stream.
17. Leaky header seats.

Bulletin TR-516 entitled "Some Experiences in Service", contains more detailed information on this timely subject, and is available upon request.

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Opinion and comment

BASIC RESEARCH IS A PROBLEM

Chemical engineers, as all engineers, are interested in basic research. We recognize that a highly developed engineering science feeds on basic research—the untiring and never-ending search for the fundamental and basic facts in Nature's storehouse. Possibly more than others, chemical engineers recognize this dependence, for, in recent years, we have had to do some of our own basic investigation to obtain the background for new developments. However, engineers are not scientists, and consequently, as a profession, we ought to show more than a passing interest in the purposes of the National Science Foundation and try to understand what is being done not only to help science in general, but also specifically to help our own profession. For the facts and figures, we went to an A.I.Ch.E. member, Ralph A. Morgen, formerly director of the Engineering Experiment Station at the University of Florida, and now Program Director for Engineering at the National Science Foundation.

The program analysis staff of the N. S. F. has found out that of the 300 million of Federal funds spent at nonprofit institutions, twenty-five per cent went into basic research: the remainder went to applied research and development.

In commenting on this division, Morgen stated that the N. S. F. felt that the figure of twenty-five per cent should be increased drastically. The reason for the feeling is, to the editor, interesting, for it shows how easily hard-boiled science and engineering draw on ideals, on non-Euclidean ethics—if we may be permitted a fancy phrase. The reason—because the aura of research in nonprofit institutions is slowly being destroyed by the emphasis on development.

One cannot quarrel with the desire to preserve the intangible research atmosphere, for, if it is not present in our universities, where will we find it? In Morgen's own words, "The important job to be done is to reverse the tendency towards increasing the applied research and development in our universities so that the percentage of basic research, as well as the total gross amount of basic research, can be increased in our educational institutions. Not only must the N. S. F. keep a balance between basic research and development, but there is necessity for keeping a balance between the basic sciences."

Another important N. S. F. basic-research relationship is a survey now under way to determine just how much basic research in engineering can be carried out in the United States. There is a limit, not only of laboratories and equipment, but also of men. As the manpower pinch becomes more serious, graduate students are becoming rare items in universities, and the capacity to do basic research is being impaired. So, along with the need to do more fundamental work, is the interesting question, can we? Preliminary results, according to Morgen, indicate that at least one hundred engineering colleges have staff members capable of conducting basic research, if the funds were available.

This editorial is to urge cooperation with the purposes of the Foundation. Chemical engineers in a position to carry out research should seek appropriations as a matter of course. Our problems are many, and the need for intelligence is great. As members of an interested profession we should do all we can to help and encourage pure science; science for science' sake.

So far the chemical engineers have fared well in obtaining grants. Out of nineteen N. S. F. engineering grants fourteen were of direct interest to chemical engineers.

As the N. S. F. increases aid to basic research, the engineering-sciences program will grow in proportion to the needs in this area compared to the needs in mathematics, biology, chemistry, or other basic areas. It is here that we need to cooperate and to understand, and to urge such a program even though it may mean sacrifice on our part. Through this, and other programs, possibly sponsored by industry, we, as a nation, may some day reverse our position in research from a debtor nation to European science to a creditor nation for the whole world.

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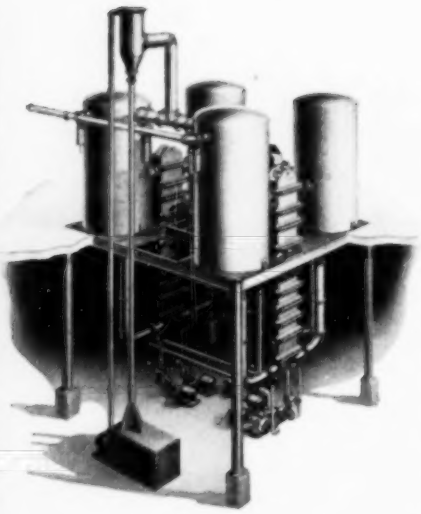

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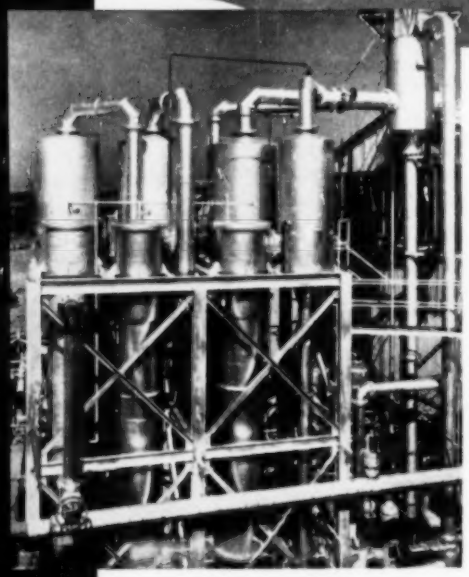

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Fluidized-Solids Technique in the Petroleum Industry

R. C. Gunness Standard Oil Company, Whiting, Indiana

The fluidized-solids technique is perhaps the major advance in chemical engineering of the past decade. In contacting gases with solid reactants or catalysts, use of a fluidized bed of solid particles leads to uniform temperatures throughout the bed, high reaction rates, and better yields. The solid particles can be easily added to and withdrawn from the reactor; circulation of the solids can be effectively used for heat transfer.

The new technique was developed in the petroleum industry during World War II; the resulting fluid catalytic-cracking process is the largest-scale catalytic operation in the world. The principle is also being used in the synthesis of liquid hydrocarbons from natural gas, and the first commercial unit employing a fluidized catalyst for the reforming of naphtha is about to go on stream. Fluid processes for obtaining oil from shale and bituminous sand have been proposed. Other industries are beginning to make use of this valuable tool in such processes as the synthesis of phthalic anhydride, the manufacture of activated carbon, the calcining of limestone, and the roasting of ores.

The fluidized-solids technique has many undeveloped potentialities and shows promise as a new research tool. Despite intensive fundamental research in recent years, much remains to be learned about the behavior of fluidized solids and the mechanism of fluidization.

The principle of the fluidization of solids may be illustrated by means of an analogy. In Figure 1 the effect of an upwardly flowing gas on a bed of solid particles is compared to the effect of temperature on the physical state of a substance under its own vapor pressure. At low gas velocities, the bed is static and corresponds to the solid state of the substance at low temperatures. When the gas velocity reaches a critical value for the system, the bed particles begin to separate and to be supported by the gas; this point is comparable to the melting point in the analogous diagram. Over a limited range of gas velocities, the bed comprises a continuous dense phase of vigorously agitated particles and resembles a boiling liquid with a well-defined surface. As gas velocity increases over this range, an increasing number of particles carried above the surface by entrainment constitute a dilute phase comparable to the vapor state. The density of the dilute phase progressively increases, while that of the dense phase decreases. The two phases thus coexist in the same way as the liquid and vapor states of a boiling liquid. A further critical increase in gas velocity results in expansion of the entire bed into the dilute phase; this transition is analogous to the disappearance of the meniscus between a liquid and a vapor at the critical temperature. Continuing expansion of the dilute phase with increasing fluid velocity is comparable to the expansion of a vapor at constant pressure with increasing temperature.

The numerical relationship between bed density and gas velocity for any given system depends on the density and particle size of the solid material and on the density of the gas. Liquids can be used as well as gases to produce fluidized beds of solid particles, but attention in this field has thus far been primarily directed to finely divided solids in gases. In such systems, particle size is the ma-

R. C. Gunness

Robert C. Gunness, a Director of A.I.Ch.E. (1951-53), is assistant general manager of the manufacturing department of Standard Oil Company of Indiana, Chicago, Ill. He has been associated with Standard Oil since 1938 except for a short period in 1951 when he went with the Department of Defense on the Research and Development Board. In his early years with Standard Oil he was group and section leader in the research department prior to becoming assistant director, associate director, and manager of research. Mr. Gunness received a B.S. degree from Massachusetts State College in 1932 and a Sc.D. in 1936 from Massachusetts Institute of Technology.

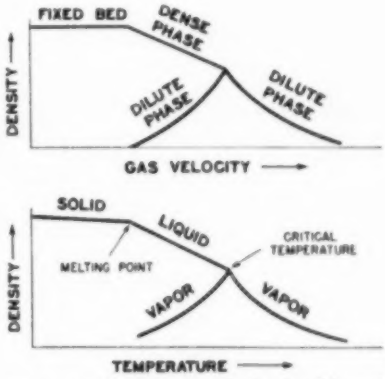

Fig. 1. Analogy between fluidized solids and physical states.

jor factor that contributes to fluidization behavior; particles of 20 to 80μ diam. are preferred for gas velocities in the convenient range of 1 to 2 ft./sec.

Characteristics of Fluidized Solids

Fluidized solids have several characteristics of value in contacting gaseous and solid reactants or, more often, gaseous reactants with solid catalysts. These features arise primarily from the ability of the fluidized mass of small particles to flow as though it were a liquid, and from the constant agitation and mixing of the particles.

The mobility of fluidized solids permits the ready transfer of solids to or from a reaction vessel without interrupting operations. Because the density of the fluidized mass can be raised by changing the gas velocity, a hydrostatic head can be used in place of pumps to effect such transfer (see Fig. 2). The

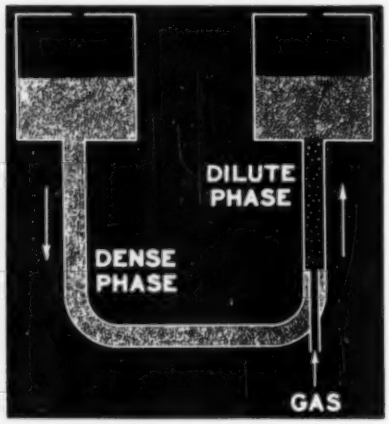

Fig. 2. Transfer of fluidized solids.

dense-phase solids in the left leg of the U-tube create a greater hydrostatic head than the dilute-phase solids in the right leg, where the gas velocity is increased by aeration. Consequently, the dense-phase leg functions as a standpipe and there is continuous flow from the left vessel to that on the right, although there may be no static pressure differential between the two. In practice, the rate of flow is controlled by means of a valve at the base of the left leg, or standpipe, and aeration at low gas velocities is maintained in the dense-phase parts of the system in order to maintain the fluid state. The standpipe must provide sufficient hydrostatic head to prevent reversal of flow and to serve as an effective seal between the two vessels.

The constant motion of the individual particles in a fluidized bed results in uniform composition of the bed. This property permits continuous addition of a solid reactant or removal of a solid product without affecting the homogeneity of the bed; it enables contact of a single solid with different gases in two or more vessels. Certain discontinuous processes can be made continuous by circulating the solids alternately through two vessels in which different reactants are carried out. Advantage can be taken of the circulating solids as an efficient heat-transfer medium.

The continuous mixing in the fluidized bed also results in the rapid transfer of heat throughout the bed. Even when endothermic or exothermic reactions occur in beds of considerable depth, no appreciable temperature differences are found. The reaction temperature can be held at the ideal level, so that side reactions are minimized and product of uniform quality is obtained.

Fluidized-solids systems are especially suitable for processes in which temperature must be closely controlled despite a high heat of reaction—positive or negative. A large reactor of simple construction can be used, heat being supplied or removed by immersed coils, by heat transfer at the walls, or by circulation of the solids through an external heating or cooling zone. Reactions that are inconveniently sensitive to temperature often can be tamed in such a reactor.

Excellent contacting is obtained in passing a gas through a turbulent mass of finely divided solids. The large surface of the fluidized particles permits high reaction rates (*12*). Channeling, frequently encountered in fixed beds, particularly with aged catalysts, is largely avoided.

Prior to 1940, the principles of fluidized solids were little understood and the technique was employed only in a primitive manner. Grain, wood chips, and sand have been blown through pipes for decades. The Winkler generator, developed in Germany about thirty years ago, gasified powdered coal suspended in a stream of oxygen and steam. Twenty years ago, Geoffrey Martin, with less success, tried to apply fluidization to a cement kiln. Full recognition of the possibilities of fluidization as an engineering tool did not begin until the search by chemical engineers in the petroleum industry for improved methods of handling cracking catalysts.

Fluid Catalytic Cracking

The major task of petroleum scientists since the advent of the automobile has been to find cheaper ways to make more and better gasoline from each barrel of crude oil. The chief means of increasing the gasoline yield is the decomposition or cracking of higher-boiling petroleum fractions. In this process, such a distillate as gas oil is vaporized and converted largely to hydrocarbons in the gasoline boiling range, lesser amounts of gas and coke being formed as by-products. When a catalyst is employed, the coke forms on the catalyst and reduces its activity, so that frequent regeneration is necessary.

The first commercial catalytic-cracking process (*4*) employed multiple fixed-bed reactors operating alternately on a cracking period and on a regeneration period during which the coke was burned off in air. Because each reactor had to be built for two different operations—one endothermic in a reducing atmosphere and one exothermic in an oxidizing atmosphere—equipment and operating costs were high. Cracking and regeneration temperatures were difficult to control, and the large amounts of heat

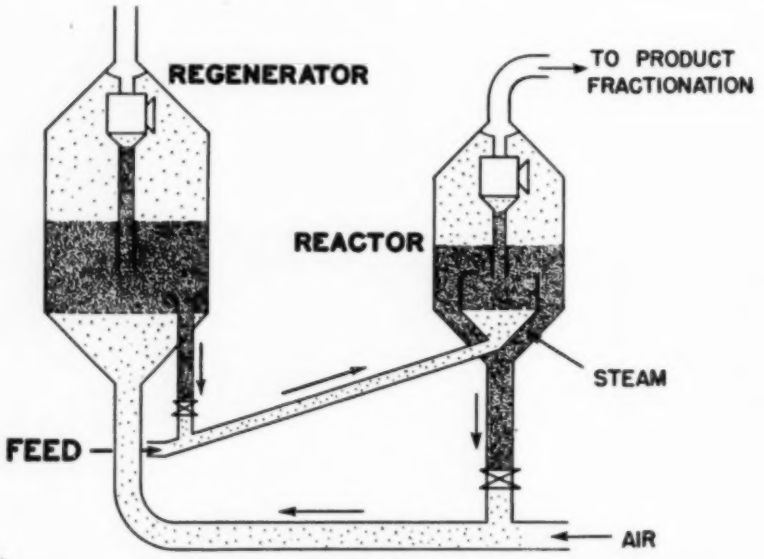

Fig. 3. Fluid catalytic-cracking process.

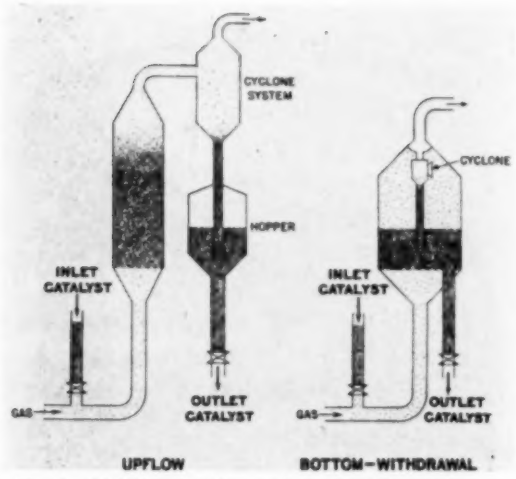

Fig. 4. Original and modern methods of catalyst circulation.

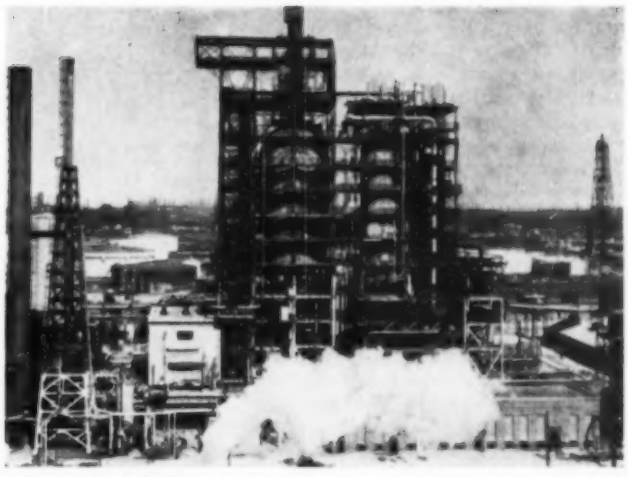

Fig. 5. Typical 25,000-bbl./day fluid cracking unit, Whiting refinery, Standard Oil Co. (Ind.).

liberated during regeneration could not be transferred efficiently to offset the substantial heat input needed to vaporize the oil and to satisfy the heat of reaction. These problems suggested the advantages of moving the catalyst back and forth between reaction and regeneration zones, and ultimately led to the fluid catalytic-cracking process.

The development of this process was spurred by the need during World War II for aviation gasoline and for synthetic rubber, the raw materials for which could best be supplied by catalytic cracking. In the short period of three years, experimental investigation of the behavior of fluidized solids and pilot-plant development of an operable process led directly to the construction, in 1941, of three 13,000-bbl./day commercial units (*14*). Problems that had to be overcome involved instrumentation, control of erosion, design of suitable valves for controlling catalyst flow, and the devising of an adequate system for recovering entrained catalyst. Although improvements have since been made in the design of fluid-cracking units, the original units are still being operated on an attractive economic basis.

Modern fluid cracking units employ essentially the process scheme shown in Figure 3. The preheated gas-oil charge is vaporized upon contact with a stream of hot, finely divided catalyst from the regenerator. The dilute-phase mixture of catalyst and oil vapor, in the ratio of about 7 lb. of catalyst/lb. of oil, passes into the dense-phase fluid bed in the reactor. Cracking takes place in this zone at about 900° F., with accompanying coke deposition on the catalyst. The reaction products are taken overhead for fractionation. Spent catalyst travels downward along the walls of the reactor, through a steam stripper for removal of adhering hydrocarbons, and into a standpipe. The catalyst is then forced by hydrostatic pressure to the regenerator, where burning of the coke raises the temperature to about 1050° F. The hot regenerated catalyst passes downward through a standpipe to contact again fresh feed and complete its cycle. Substantially atmospheric pressure is maintained in both the reactor and regenerator.

Huge quantities are involved in fluid-cracking operations; no other catalytic reaction is carried out on such a scale. A 25,000-bbl./day unit contains about 500 tons of catalyst—either synthetic silica-alumina, or activated natural clay—circulating at the rate of 20 tons/min. The circulating catalyst provides efficient transfer of more than 100 million B.t.u./hr. from the regenerator to the reactor. Highly important to the process are the uniformity of temperature in the fluidized reactor and regenerator beds and the ease with which catalyst regeneration continuously supplies preheat to the feed and maintains cracking temperature in the reactor.

The major change in the process between the first commercial units and those built subsequently lies in the method of removal of catalyst from the reactor and regenerator (Fig. 4). In the original units, all of the catalyst was passed overhead in the dilute phase through a costly system of cyclones to separate it from the vapor. Catalyst circulation was limited, so that full advantage could not be taken of it for heat transfer; large feed preheaters and regenerator catalyst coolers were therefore required. Operating flexibility was severely limited by considerations of catalyst holdup, reactor gas velocity necessary for adequate catalyst circulation, and reactor height needed to provide the required reaction time.

Units of later design operate on the principle of withdrawal from the bottom of the fluidized beds. With this arrangement, catalyst is transferred in the dense phase, and the problem of solids recovery is materially reduced. Higher rates of catalyst circulation are possible, because less than 1% of the circulating solids are entrained in the exit gases; a comparatively simple cyclone returns the bulk of these solids to the dense-phase bed through an internal standpipe, or dipleg. The rate of catalyst circulation can be varied to make better use of regeneration heat and to give greater flexibility of operation. A major advantage of the bottom-withdrawal design is that the depth of the bed, and consequently the degree of contact and extent of reaction, can be set at will. A typical 25,000-bbl./day unit of this type is shown in Figure 5.

Experience in operating catalytic-cracking units and further process developments have led to a number of modifications primarily directed toward simplifying design and reducing investment and operating costs. Better utilization of the circulating catalyst as a heat-transfer medium has reduced the need for feed preheating and regenerator cooling. Expensive Cottrell precipitators, used on early bottom-withdrawal units to recover catalyst fines passing through the cyclones, have been eliminated by the use of multistage cyclones. Further knowledge of the minimum standpipe pressure differentials necessary to prevent reversal of flow has permitted substantial reductions in the length of the standpipe, with corresponding reductions in the height of the units and hence in the structural-steel requirements. In some recently built units, the steel costs have been pared by superimposing the reactor on the regenerator. Other process and mechanical developments include improvements in regenerator linings, contour designing of catalyst-transfer lines to reduce erosion, refinements in the construction of the reactor and steam stripper that permit higher feed rates, and simplification of controls.

The predominant characteristic of the modern fluid cracking process is flexi-

bility. A variety of feed stocks can be cracked over a wide range of temperatures and conversion levels, so that the process is adaptable to diverse refinery yield and quality requirements. The adaptability of the process has led to rapid acceptance and widespread use of fluid cracking. Figure 6 graphically illustrates the tremendous growth of the process in the eleven years since the first units were placed on stream. Installed design capacity is now about 1,400,000 bbl./day, two thirds of which has been placed in operation since the war. The fluid process accounts for well over half of all catalytic-cracking capacity.

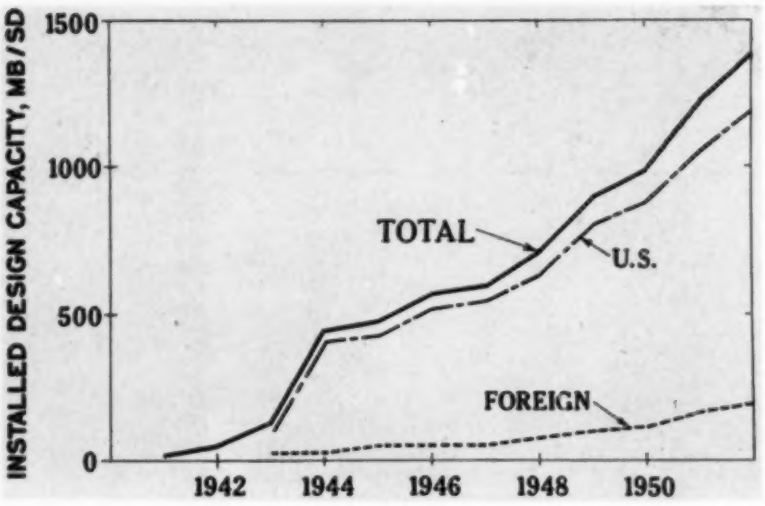

Fig. 6. Growth of fluid catalytic-cracking process.

Fluid Hydroforming

Attention has also been given by petroleum scientists to improving the quality of the gasoline components obtained *directly* from crude oil. A modification of thermal cracking, known as naphtha reforming, began to be applied in the late 1920's to petroleum fractions boiling within the gasoline range. The success of fixed-bed catalytic cracking led to the development, by 1939, of the first catalytic naphtha-reforming process, called hydroforming.

In this process, naphthenic hydrocarbons present in the naphtha are dehydrogenated to aromatics over a molybdenum or platinum catalyst. Fixed-bed hydroforming came into prominence during World War II for the synthesis of nitration-grade toluene and aviation-gasoline components. The process is being used today not only for raising the octane number of gasoline blending stocks but also for the manufacture of much-needed benzene and other aromatics.

The knowledge about fluidized solids gained in developing fluid cracking has led to extensive experimental work on applying the new technique to hydroforming. A fluid hydroforming process (a) would have simpler equipment than the fixed-bed process and hence lower investment and operating costs, (b) would permit continuous operation under isothermal conditions with continuous regeneration of catalyst, and (c) would give better catalyst life because of better control during regeneration. Process-development studies have been carried out on a 3-bbl./day pilot plant and subsequently on a 50-bbl./day unit (*18*). Figure 7 shows the first commercial-scale fluid hydroformer, about to be placed in operation at Destrehan, La.

Essential features of the fluid hydroforming process (17) are shown in Figure 8. Naphtha feed, preheated to about 950° F., and hydrogen-rich recycle gas, preheated to about 1300° F., are passed under 250-lb. pressure into the reactor. Product vapors flow through a two-stage cyclone to the recovery section, where fractionation and stabilization produce essentially a finished gasoline.

Regenerated catalyst flows into the reactor, where turbulent mixing with hydrocarbon vapors provides efficient contacting. Spent catalyst is lifted by a stream of recycle gas through a riser into the hopper above, from which it flows through a standpipe into the regenerator. The small amount of catalyst deposit is burned off in air under 260 lb. of pressure and at about 1100° F. Surplus heat is removed by water tubes partially submerged in the fluidized bed; regenerator temperature is controlled by varying the catalyst-bed level and hence the degree of submergence of these tubes. Catalyst-circulation rate is controlled by the rate of gas injection in the spent-catalyst riser in the reactor.

The superiority of the fluid process over the conventional fixed-bed process has been demonstrated in extensive pilot-plant studies. In addition to the anticipated economies and advantages of isothermal operation, the fluid process represents a definite improvement from the yield standpoint. With either a molybdenum or a platinum catalyst, fluid hydroforming can produce as much as 5% more gasoline than does the fixed-bed process, largely because of a reduction in the yield of gas (*13*). The fluid process possesses greater flexibility with regard to feed-stock boiling range and composition, and can produce higher-octane gasoline without serious yield disadvantages. The trend toward en-

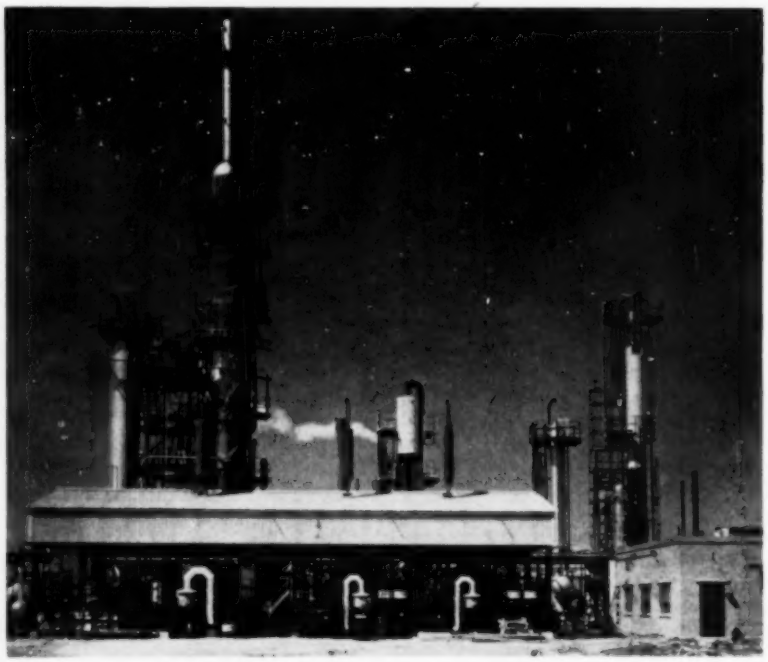

Fig. 7. First commercial fluid hydroformer, Destrehan refinery, Pan-Am Southern Corp.

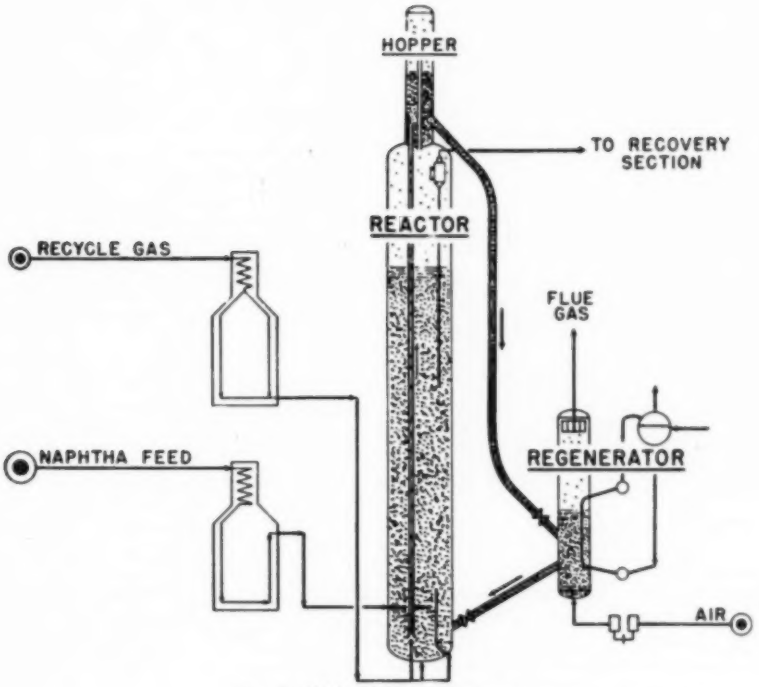

Fig. 8. Fluid hydroforming process.

gines of higher compression ratio and toward higher-octane fuels can be expected to bring fluid hydroforming to the forefront among petroleum-refining processes.

Hydrocarbon Synthesis

Fluidized solids are also finding application in the long-range problem of supplementary sources of liquid hydrocarbons. This technique is being employed commercially in the synthesis of liquid hydrocarbons by the hydrogenation of carbon monoxide. In the current hydrocarbon-synthesis process, natural gas is partially burned with oxygen to produce a mixture of hydrogen and carbon monoxide. When the mixture is passed through a bed of fluidized catalyst, the two components react to produce liquids that range from gasoline to heavy fuel oil, and a variety of oxygenated compounds are made as by-products. The reaction is highly exothermic; rigid temperature control is necessary to prevent overheating and consequent degradation of the products to methane, carbon dioxide, and carbon. The isothermal nature and heat-transfer characteristics of the fluidized bed make this technique attractive in the hydrocarbon-synthesis process.

Essential features of the process (*5, 11, 15*) are shown in Figure 9. Oxygen and excess natural gas are passed into the synthesis-gas generator, where partial combustion raises the temperature to 2400° F. No catalyst is used, and temperature is controlled by steam generation. The effluent 2:1 mixture of hydrogen and carbon monoxide is cooled, scrubbed, and charged in admixture with recycle gas to the bottom of the reactor. Here the gases contact a fluidized bed of iron catalyst at 600° F., temperature being controlled by steam-generating tubes. The reaction products, freed of entrained catalyst by a cylone, are condensed in a primary separator, from which a water layer containing water-soluble chemicals is withdrawn and the gas and oil phases are sent to product-recovery facilities. The gas recovered is high in olefins and can be converted to additional gasoline by polymerization. The oil-soluble chemicals can be either recovered as such or converted to olefins. Such further processing can give a finished high-octane gasoline representing about 90% of the reaction products.

At the relatively high reactor temperature, free carbon is formed and causes some disintegration of the catalyst. The present process is nonregenerative, but the catalyst is cheap and the use of the fluidized bed permits continuous catalyst replacement.

The first commercial hydrocarbon-synthesis plant, at Brownsville, Tex., was designed to convert 100 million cu. ft. of natural gas/day into 7700 bbl. of liquid products. The process is not yet economically competitive with crude-oil refining as a means of producing liquid hydrocarbons, but the by-product oxygenated compounds, amounting to 450,000 lb./day, provide the economic incentive. Hydrocarbon synthesis can be expected to become more important in future years as crude oil becomes increasingly expensive to bring to the surface. A similar process employing pulverized coal as the raw material is even less economical, but sufficient pilot-plant work has been carried out to demonstrate operability.

Oil from Shale or Bituminous Sand

The successful use of fluidized solids as catalysts for hydrocarbon-conversion reactions has hastened consideration of the technique in noncatalytic applications quite unrelated to present-day petroleum refining. Of particular interest to the petroleum industry is the experimental work being carried out on the production of oil from oil shale or bituminous sand. On the basis of pilot-plant studies, processes employing the fluidized-solids technique have been proposed for both source materials. Although these raw materials can not yet compete with crude oil, they may have commercial significance in future years.

A proposed scheme for the retorting of oil shale (*15*) is shown in Figure 10. The process consists essentially of a retort in which the shale is decomposed, a burner to supply process heat, and a solids-circulating system for transferring heat and conveying shale to and from the processing zone. Shale rock is ground to suitable size and fed through a standpipe into a hot spent-shale stream from the burner. The com-

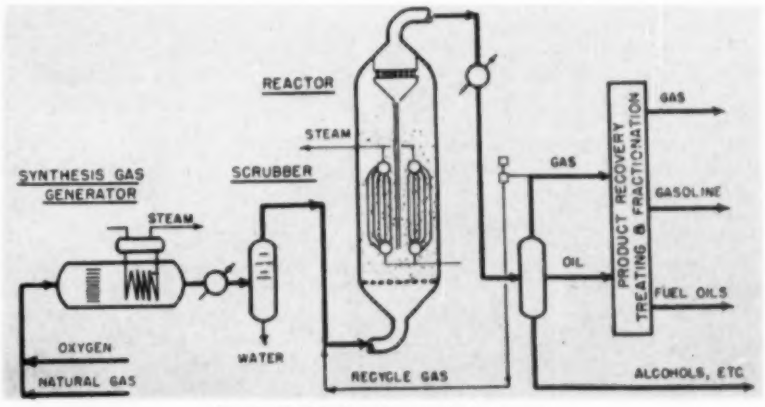

Fig. 9. Fluid hydrocarbon-synthesis process.

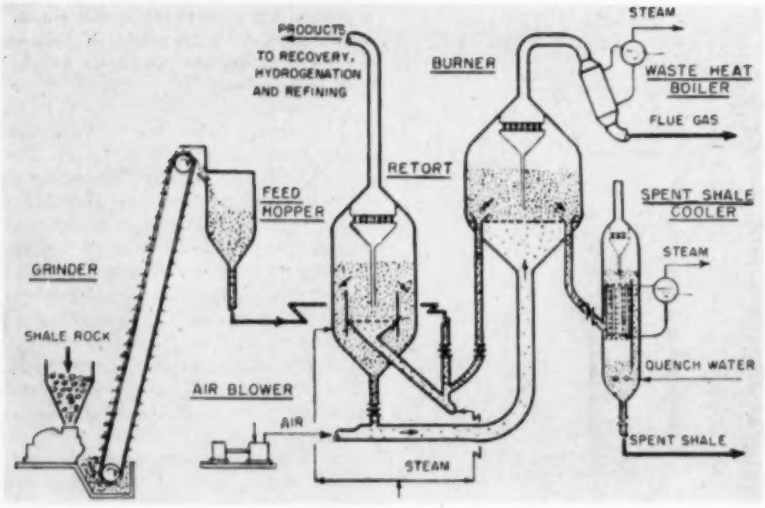

Fig. 10. Fluid process for retorting oil shale.

bined stream flows into the retort to maintain a dense-phase fluidized bed at 850-1000° F. The liberated hydrocarbon vapor is taken overhead through a cyclone system to the extensive refining facilities needed to convert shale oil to usable products. Spent shale is transferred in the dilute phase to the burner, where combustion of residual carbonaceous material supplies the heat requirements of the process plus waste heat recovered from a portion withdrawn through a cooler.

Experimental work on the recovery of oil from the vast deposits of bituminous sand in northern Alberta has led to the recently proposed (*16*) distillation-coking process outlined in Figure 11. Bituminous sand is fed continuously into a bed of burnt sand, fluidized with steam and maintained above 900° F. The oil product is carried by the fluidizing steam through a cyclone separator to the fractionating column for product recovery. Spent sand is circulated continuously from the bottom of the still to the burner for combustion of the residual coke. Return of hot sand through the burner standpipe transfers sufficient heat to the still for the distillation step. Each ton of sand charged yields about two-thirds of a barrel of oil. A similar process has been suggested for the simultaneous dehydration and coking of the wet oil obtained from bituminous sand by the water-flotation method (*9*).

Applications in Other Industries

Whereas the petroleum industry developed the fluidized-solids technique, is now using it extensively, and may well rely more heavily on it as alternative sources of oil become important, other industries are also beginning to make use of this valuable tool.

A plant in Chicago is producing phthalic anhydride by the oxidation of naphthalene in a fluidized bed of vanadium catalyst (*8*). As there is no poisoning or loss of catalyst, no regeneration or catalyst-replacement facilities are needed. Because the isothermal operating conditions permit lower reactor temperatures than are used in the conventional process, the fluid process yields directly a product of higher purity.

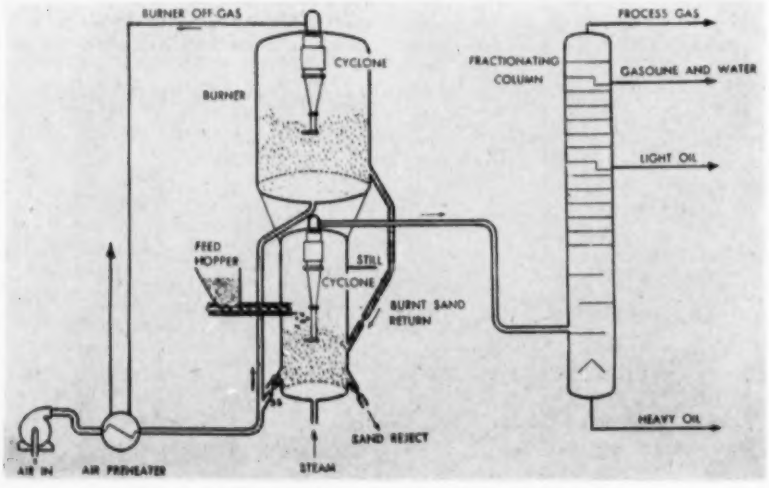

Fig. 11. Fluid process for recovery of oil from bituminous sand.

The fluidized-solids technique is being used in France for the manufacture of activated carbon by treatment of pulverized carbonaceous material in a fluidized bed with an upwardly flowing mixture of air, combustion gases, and steam (*7*). The more uniform temperature results in higher yields than are obtained in conventional kilns. A similar process was employed in this country during World War II for making activated carbon from nut shells.

Fluid processes for the gasification of coal have been studied in this country and in England, but have not yet been commercialized. In these processes (*2, 8*), pulverized coal is fed into a hot fluidized bed of coke particles and treated with oxygen and steam. Cyclone separators remove entrained coke from the water-gas product, and ash is eliminated as necessary to control the level of the fluidized bed. These processes may some day become important for the generation of synthesis gas for hydrocarbon synthesis starting with coal rather than natural gas.

In a new process for the calcining of limestone (*10*), the thermal advantages of countercurrent operation are combined with the uniformity of temperature provided by fluidized beds. Several fluidized beds are superimposed in a single reaction vessel. Crushed limestone flowing downward through the beds is preheated by contact with a rising flue-gas stream and is calcined in the fourth bed at about 1700° F., maintained by burning heavy fuel oil sprayed directly into the bed. This process yields lime of good quality and color despite the direct contact with burning fuel oil.

In a somewhat different application being developed in England (*3*), granular materials are transported over considerable distance by means of an "air-slide," or fluidized-solids conveyor. This device consists of a trough divided by a layer of porous ceramic tiles into a closed lower trunk and an open trough. Air under a slight pressure in the trunk passes upward through the tiles, fluidizes the material to be transported, and enables it to flow as a liquid along the trough at an inclination of only a few degrees.

Other applications—largely in the fields of fuels and metallurgy—have been suggested. The roasting of gold ore in the fluid state has been practiced in this country and in Canada for almost five years, and commercial-scale roasting of copper and zinc sulfides is beginning (*6*). A fluidized-solids nuclear reactor has been successfully operated at Oak Ridge (*1*). Other proposed applications include the reduction of metal oxides; sulfation of copper oxide; hy-

drogenation of coal; carbonization of coal; removal of hydrogen sulfide from fuel gas; and removal of mists and dusts from air. Few of these processes have yet been developed to the pilot-plant stage.

Conclusion

The fluidized-solids technique is still in its infancy. Of the large number of chemical reactions that could be effectively carried out in a fluidized bed, only a few have as yet actually been studied under such conditions. Commercial applications have been limited to fluidization of catalysts or reagents in gases. The commercial possibilities of systems involving liquids as the fluidizing agents are essentially unexplored.

The fluidized-solids technique also shows promise as a research tool. The opportunity that it provides for continuous sampling of a reaction bed offers a new avenue of exploration of the physical and chemical behavior of solids during reaction and of changes in the activity of catalysts. This technique—coupled with the use of radioactive tracers, for example—can be expected to make major contributions to our knowledge of the nature of catalytic action.

The full scope of the concept of fluidization is only beginning to be recognized. The fundamental principles of particle contacting that are being discovered apply not only to solids in fluids but generally to two-phase systems in which one phase is finely dispersed throughout the other. Such apparently unrelated phenomena as ore flotation, liquid-liquid extraction, and spray drying are examples of fluidization in the broad sense. New knowledge about any of these phenomena will ultimately contribute to the fuller understanding of all of them.

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Discussion

John Griswold (General Chemical Division, 40 Rector St., New York): The slide on hydrocarbon synthesis showed steam coils in the converter to remove heat of reaction. Can you give any details of the gas temperature range in the converter and how much heat can be removed by heat transfer to steam?

R. C. Gunness: This particular reaction is carried out at a temperature of around 600° F. However, I think that probably the best way to deal with your question is to note that heat-transfer coefficients in the range of from 40 to 50 B.t.u./(hr.)(sq.ft.)(° F.) are conventional for fluidized beds although in the case of hydrocarbon synthesis they rise to 100.

F. B. White (Foster Wheeler Corp., New York): In discussing fluidized technique, you cited catalytic production of phthalic anhydride. I believe you stated a pure product was obtained by employing a fluid catalyst. This would be significant if you can relate the purity of the naphthalene feed stock used in this plant with that used in other plants. Is it possible for you to do this?

R. C. Gunness: No, I'm sorry, I'm afraid I cannot. It is my understanding that owing to the isothermal character of the fluid operation with phthalic anhydride, less side reactions occur than would be the case with an adiabatic static bed where constant temperatures do not prevail.

Merk Hobson (University of Nebraska, Lincoln, Neb.): The hydroforming process proceeds in an atmosphere of hydrogen. Are there any special problems involved in the transfer from the fluidizing media in the reactor to that in the regenerator?

R. C. Gunness: A problem of the fluid process is to keep the reactants out of the regenerator and the oxygen out of the reactor. This is accomplished through the use of stripping zones in which steam or recycle gas is used as stripping agent. There obviously are certain amounts of the reactants that do get over into the regenerator and conversely a certain amount of the flue gas in the regenerator is transferred into the reactor. But the amounts are small and in terms of the process considerations involved are really unimportant. In this regard the situation is not different in fluid hydroforming from what it is in fluid catalytic cracking.

R. H. McBride (Du Pont Co., Lewiston, N. Y.): What is the experience of the petroleum industry with baffles in its reactors to improve fluidization?

R. C. Gunness: Extensive investigations have been carried out on the use of baffles, particularly in connection with small-scale pilot-plant equipment, in an effort to induce fluidization under conditions where gas velocities and the configuration of the apparatus are not such as to give satisfactory fluidization.

In general, as far as commercial operations are concerned, we do not feel it necessary or desirable to include baffles to enhance fluidization further. As a matter of fact, we look upon such surfaces as destructive of fluidization rather than inducing it.

There are cases of course, where heat-transfer surfaces are put within the reaction vessel and in such instances care must be taken to assure that the surface is not destructive of satisfactory mixing and turbulence within the vessel. In general, we do not find it desirable to use baffles for the specific purpose of creating turbulence.

J. V. Ward (Gulf Research & Development Co., Harmarville, Pa.): Although in describing fluidization we always speak of it as giving a very uniform temperature level, do you know any work being carried on which is studying localized and instantaneous temperature measurements in a fluidized bed?

R. C. Gunness: I can't say that I do have any information along those lines. We have all wondered if it is not possible that individual catalyst particles which have carbon on them are grossly overheated, even though the apparent temperatures in the fluid bed are uniform.

Although I know of no direct measurements, we certainly have evidence that high local temperatures do not exist. Catalysts which we know are deactivated by high temperatures are not deactivated under conditions in a fluidized bed. This appears to me to be evidence that we do not have very high local temperatures in a fluidized bed.

J. V. Ward: I was thinking in terms of the regenerator where the average level is 1100° F., but the catalyst would not be harmed until it reached a temperature level of about 1300°-1700° F. So there could be that range above a normal level of 1100° F. up to 1200° or 1300° F. for some instantaneous time in an extremely localized zone. However, the specific type of catalyst used and the presence of high-temperature steam must both be properly evaluated before a more exact deactivation temperature level can be given. A source of steam-aging of cracking catalyst is available that indicates the above-quoted range for the deactivation of catalyst at an elevated temperature (*1*).

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(Presented at A.I.Ch.E., Chicago, Ill., Meeting.)

Absorption of Hydrogen Fluoride in a Limestone-Packed Tower

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Data for absorption of hydrogen fluoride from gas stream in a limestone-packed tower are presented to cover the effect on absorption coefficients of fraction of limestone packing that has reacted with hydrogen fluoride, gas velocity and temperature, size of packing, concentration of hydrogen fluoride, and type of limestone used. The absorption coefficients were found to vary linearly with the 0.8 power of mass velocity, and the logarithms of the absorption coefficients were directly proportional to the absolute temperature of the gas. The effect of particle size and fraction of limestone reacted was correlated graphically using a parameter involving these variables. Absorption coefficients of different limestones were found to vary widely and to be higher for dimensionally unstable (oolitic) varieties. The data and the correlations obtained were used to calculate depths of packing required to absorb a desired fraction of hydrogen fluoride from the gas concomitant with a given calcium fluoride content.

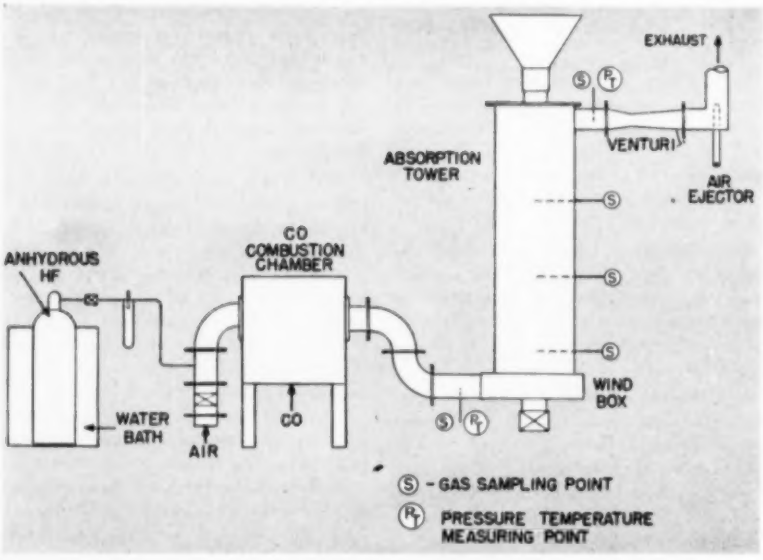


Fig. 1. Limestone-packed-tower system for recovery of fluorine.

IN May 1949 the Tennessee Valley Authority placed in operation equipment for the removal of fluorine from the stack gas from the manufacture of fused tricalcium phosphate at its Columbia, Tennessee, demonstration plant. Fluorine removal from fused tricalcium phosphate is accomplished by passing hot stack gas through a tower packed with lump limestone and is based on the absorption of hydrogen fluoride present in the gas. The pilot-plant-scale development of the process was described by Hignett and Siegel (*3*). The present paper describes small-scale engineering studies that preceded and accompanied the pilot-plant work. The data obtained in these studies were used to define the relationship between the absorption coefficients and experimental variables such as temperature, gas velocity, concentration of hydrogen fluoride in the gas, and particle size of limestone. An empirical relationship was demonstrated between absorption efficiency of limestone and a parameter determined by the particle size and the fraction of limestone reacted. This relationship can be used to calculate the depth of packing required to absorb a desired fraction of the hydrogen fluoride entering the bed concomitant with a product of a desired calcium fluoride content.

Equipment and Procedure

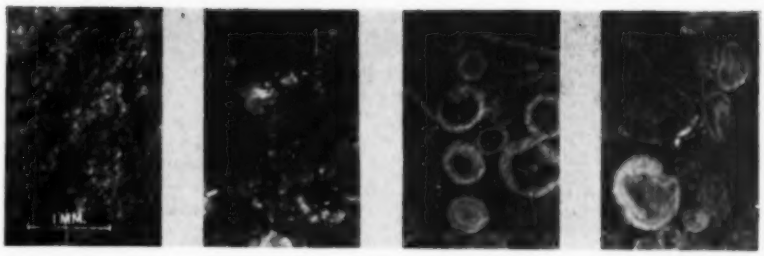
The test procedure consisted in passing a stream of air containing carbon dioxide, water vapor, and hydrogen fluoride through a tower packed with sized limestone. The equipment used in these tests is diagramed in Figure 1; it consisted of a hydrogen fluoride supply system, a combustion chamber in which carbon monoxide was burned and products of combustion were mixed with hydrogen fluoride and air, a tower packed with limestone, and auxiliary equipment used for the control and measurement of the experimental variables. Although fluorine-containing stack gas was available from a small pilot-plant shaft furnace for the experimental production of

fused tricalcium phosphate, simulated stack gas was used in these tests to permit closer control and wider variation of variables. The simulated gas was produced by injecting a measured, constant stream of anhydrous hydrogen fluoride into a stream of air, which in turn was mixed with products of combustion of carbon monoxide. The flow of gas through the system was maintained by means of a compressed-air ejector and was measured with a Venturi meter in the exit line from the packed tower. Combustion of carbon monoxide was used both to heat the gas to the desired temperature and to provide carbon dioxide. A recording potentiometer and controller was used to measure the temperature of the gas as it entered the tower and to operate a flow-control valve in the CO supply line.

The system that was used to supply a small, controlled stream of hydrogen fluoride (0.5 to 2.0 lb./hr.) is shown in Figure 1. Hydrogen fluoride was obtained from a 100-lb. cylinder placed in a thermostatically controlled water bath and mounted on platform scales. Hydrogen fluoride flow was measured by means of an orifice drilled in a sterling-silver disk, and Monel tubing and fittings were used. To prevent condensation of hydrogen fluoride, the line that contained the orifice meter was heated electrically. The pressure drop across the orifice was measured by means of a differential manometer constructed of copper and glass tubing in such a manner that hydrogen fluoride was in contact only with the copper and the confining fluid, which was red oil. The latter reacted slowly with hydrogen fluoride and therefore was replaced periodically. The flow rate indicated by the orifice meter was checked against the decrease in weight of the cylinder for every 8-hr. interval.

The gas that contained hydrogen fluoride was introduced into the bottom of the packed tower through a wind box around the periphery of the mild-steel tower, which was 13.5 in. I.D. and 4 ft. high. The tower was equipped with a hopper and a plug valve on top, for the charging of limestone, and a plug valve at the bottom for the removal of reacted material from the tower bottom. Copper tubes were installed in the inlet and exit lines and at three levels in the tower to permit sampling of the gas. The fluorine content of the gas was determined by passing the gas through a series of three bubblers that contained 10% NaOH solution and analyzing the solution for fluorine by the modified Willard-Winter distillation method (*4*). Sampling was continuous for approximately 6 hr. in each 8-hr. tower-operating interval, and the fluorine concentrations obtained were taken to represent the average concentration for the interval.

The four different limestones used had the chemical compositions given in Table 1. Their structure is described below and is shown by the photomicrographs of Figure 2. Limestone *A* was used in a series of eight tests, lasting from 42 to 102 hr., to study the effect of experimental variables upon absorption of hydrogen fluoride. Limestones *B*, *C*, and *D* were used in five tests to study their relative absorption efficiencies.



Limestone *A*
Fractured section showing compact, fine-grained structure (nonoolitic); mined near Godwin, Tenn.

Limestone *B*
Fractured section showing compact, fine-grained structure (nonoolitic); mined near Knoxville, Tenn.

Limestone *C*
Fractured section showing oolitic structure; mined near Anderson, Tenn.

Limestone *D*
Fractured section showing oolitic structure; mined near Cowan, Tenn.

Fig. 2. Photomicrographs showing structure of limestones used for hydrogen fluoride absorption

Limestones *A* and *B* were dark gray in color and exhibited a compact and fine-grained structure. Microscopic examination showed them to consist of massive aggregates of calcite crystals scattered throughout the matrix of randomly oriented crystallites. The oolitic limestones (*C* and *D*) were of a lighter gray color and consisted of oolites, 0.25 to 0.75 mm. in size, cemented with fine-grained calcite material. The outer envelopes of oolites appeared lighter in color and chalky. Some of the oolites in limestone *C* were cemented rather loosely in their sockets; whereas the oolites in limestone *D* were firmly cemented and exhibited a microcrystalline structure.

Absorption of hydrogen fluoride by the nonoolitic limestone and the concomitant conversion of the calcium carbonate to the fluoride formed a fluoride envelope of fairly uniform thickness surrounding a nucleus of unchanged carbonate. The envelope was softer than the parent material, but it adhered firmly to the unchanged core and showed a sharp line of demarcation (Figure 3*A*).

TABLE 1
Source, Composition, and Type of Limestone Used for Absorption of Hydrogen Fluoride

Symbol	Quarry and location	Type	Composition, % CaO	F	MgO	SiO_2	Ignition loss	H_2O
A	Columbia Rock Products, near Godwin, Tenn.	Compact, nonoolitic	51.0	0.4	1.2	1.2	44.0	3.0
B	Lebanon Quarry, near Knoxville, Tenn.	Compact, nonoolitic	53.3	0.1	0.9	1.9	42.8	0.1
C	Cowan Quarry, near Anderson, Tenn.	Oolitic	54.8	0.2	0.5	0.2	43.7	0.1
D	Crab Orchard Quarry, near Cowan, Tenn.	Oolitic	54.7	0.1	...	0.7	43.6	0.1

Fig. 3A. Photomicrograph showing partially reacted nonoolitic limestone. Note: Fractured sections. The unreacted material appears as dark areas.

Fig. 3B. Photomicrograph showing partially reacted oolitic limestone. Note: Fractured sections. The unreacted material appears as dark areas.

Table 2.—Summary of

Test No.	Duration	Limestone used* Type	Size fraction	Inlet gas Temp., °F.	Rate, cu.ft./min. (N.T.P.)	HF concentration, lb. F/1000 cu.ft.	0 to 8	8 to 16
1	92	A	— ¼ in. + 6 mesh	702	47.8	0.368	99.9	99.7
2	83	A	— ½ + ¼ in.	222	51.5	0.300	99.5	97.2
3	86	A	— ½ + ¼ in.	706	34.7	0.362	99.6	99.1
4	83	A	— ½ + ¼ in.	703	46.5	0.394	99.5	98.0
5	78	A	— ½ + ¼ in.	707	76.8	0.346	99.0	96.0
6	102	A	— ½ + ¼ in.	903	48.9	0.375	99.7	98.9
7	78	A	— ¾ + ½ in.	706	46.5	0.423	96.5	86.5
8	42	A	— ¾ + ½ in.	703	46.5	0.381	98.4	90.5
9	48	B	— ½ + ¼ in.	707	47.5	0.370	99.9	99.6
10	110	B	— ½ + ¼ in.	710	48.1	0.310	99.9	99.7
11	29	C	— ½ + ¼ in.	704	51.9	0.343	99.5	99.2
12	64	C	— ½ + ¼ in.	707	46.3	0.412	—	—
13	83	D	— ¾ + ½ in.	708	48.0	0.320	99.8	99.5

* In all tests the charge consisted of 3.104 cu.ft. of limestone. The packing limestone B, 86.3 lb./cu.ft.; limestone C,

In the case of oolitic material (Figure 3*B*), absorption and reaction of hydrogen fluoride formed a relatively frail envelope that could be removed by rubbing with the fingers or by tumbling the material. The envelope of calcium fluoride that formed on oolitic limestone *C*, which showed a greater proportion of chalky material (fine calcite crystals), was softer than the envelope that formed on oolitic limestone *D*, in which less chalky material was present. In operation of the packed tower, considerably more fines having a high calcium fluoride content formed when the tower was packed with limestone *C* than when the packing was limestone *D*.

Experimental Results

The concentration of hydrogen fluoride in the gas as it entered and left the packed tower was determined by analyses of the absorbent solutions, and the results were used in calculating the amount of hydrogen fluoride that was removed in successive 8-hr. periods in each test. The percentages of hydrogen fluoride removed along with experimental conditions for thirteen tests are given in Table 2.

The data show that, under all conditions of operation, percentage removal of hydrogen fluoride decreased with time. The decrease in the rate of hydrogen fluoride absorption can be explained qualitatively by the formation on each limestone particle of an envelope of calcium fluoride, which increased in thickness with time and presented a progressively larger resistance to diffusion.

Because of the effect of the envelope, the thickness of which depends upon the extent of the limestone conversion, a study of the effect of variables—temperature, rate of gas flow, and pebble size—necessarily must be made at constant fractions of limestone reacted. The fraction of limestone converted to calcium fluoride a (average for the entire bed) was calculated for each 8-hr. period in each test using material-balance data. The reliability of this method of calculations was demonstrated by comparing the calculated degree of conversion of the entire bed with that determined by the chemical analysis of the partially reacted limestone at the end of each test; in all cases the agreement was well within 5%. Hydrogen fluoride removals then were plotted vs. fraction of limestone reacted.

Over-all absorption coefficients $K_G a$, pound-moles of hydrogen fluoride absorbed per hour per cubic foot of packed bed per atmosphere logarithmic mean of partial pressure of hydrogen fluoride, for equal fractions of limestone reacted are presented in Table 3.

The log mean partial pressure of hydrogen fluoride used in the formulation of $K_G a$ is the logarithmic mean of partial pressures of hydrogen fluoride in the gas entering and leaving the packed bed. The use of this quantity as the driving force of the process is justified by data of Domange on the equilibrium in the system CaO—HF (*2*), from which it was estimated that, in the temperature range used, the vapor pressure of hydrogen fluoride above CaF_2 was less than 0.1% of the lowest partial pressure of hydrogen fluoride encountered.

Effect of Gas Velocity. The effect of mass velocity of the gas on absorption rate is shown by tests 3, 4, and 5, in which the gas rate was the only variable. The log-log plot of absorption coefficients vs. mass velocity (Figure 4) is a family of parallel straight lines, with a slope of 0.8, one for each value of a, fraction of limestone reacted. The proportionality of $K_G a$ to the 0.8 power of mass velocity of the gas indicates that absorption of hydrogen fluoride by limestone in a packed bed is controlled largely by the resistance of the gas film.

Effect of Temperature. The effect of temperature of the gas on rate of hydrogen fluoride absorption is shown by comparison of data from runs 2, 3, 4, 5, and 6, in which temperatures ranging from

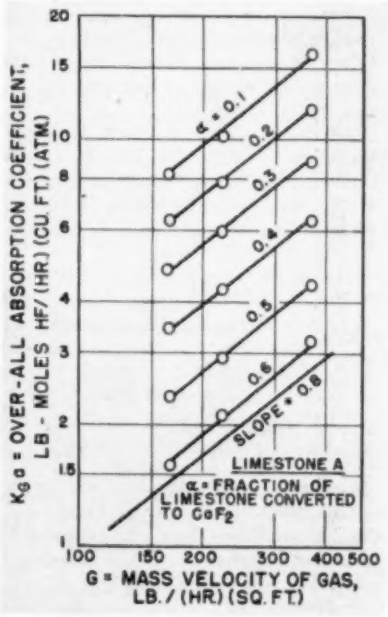


Fig. 4. Effect of mass velocity of gas on absorption coefficient.

Experimental Data

Period, hr. from start of test							
16 to 24	24 to 32	32 to 40	40 to 48	48 to 56	56 to 64	64 to 72	72 to 80
Average HF removal in packed bed, % of input							
99.4	99.0	98.2	96.8	93.8	90.2	86.3	81.8
89.8	79.3	69.0	60.3	53.5	47.8	43.5	40.5
98.2	97.1	95.5	92.8	88.4	82.5	76.3	71.0
95.7	92.5	86.3	77.6	69.8	62.7	56.2	50.8
89.0	79.5	66.5	58.0	51.0	44.5	40.0	37.0
97.5	95.1	90.5	84.6	77.0	68.5	59.0	49.0
74.0	63.5	55.0	47.5	41.8	37.5	35.4	34.1
78.3	68.2	60.0	54.5	—	—	—	—
99.3	97.8	94.5	90.0	—	—	—	—
99.5	99.0	97.5	94.2	89.8	84.3	78.0	70.8
98.8	98.4	—	—	—	—	—	—
—	—	98.0	96.8	94.0	88.2	79.3	69.5
98.0	94.2	89.0	83.5	77.5	71.3	64.5	57.8

densities of limestones used were as follows: Limestone A, 90.6 lb./cu.ft.; 84.1 lb./cu.ft.; and limestone D, 82.2 lb./cu.ft.

222° to 903° F. were used. To obviate the effect of gas velocity, absorption coefficients were divided by $G^{0.8}$, and comparison was again made for each value of a. Plot of $K_G a/G^{0.8}$ vs. T, where T is in degrees Rankine (Figure 5), shows that absorption rate increases with temperature and that log $K_G a/G^{0.8}$ is proportional to T; the relationship differs for different fractions of limestone reacted, and the proportionality constant (slope of the line) varies from 2×10^{-4} to 9×10^{-4} for $a = 0.1$ and 0.5, respectively.

Effect of Particle Size. Three size fractions of crushed limestone were used. In Table 2 the particle size is designated by the nominal sizes of the screens used to prepare the given size fraction. In calculating the specific-reaction areas and thicknesses of fluoride layers of partially

Table 3.—Absorption of Hydrogen Fluoride in Limestone—Over-all Absorption Coefficients

Test No.	Average limestone particle diameter, in.	Mass velocity of gas, G*		Per cent of limestone reacted						
				10	20	30	40	50	60	70
1	0.188	226	$K_G a$†	14.7	12.4	10.6	8.8	7.1	5.7	4.6
			$\frac{K_G a}{G^{0.8}}$	0.192	0.162	0.138	0.115	0.093	0.074	0.060
			$\frac{S‡}{t} \times 10^{-6}$	660	294	172	111	75	50	33
2	0.360	247	$K_G a$	9.5	5.0	3.1	1.9	1.0	.....	.....
			$\frac{K_G a}{G^{0.8}}$	0.115	0.061	0.038	0.023	0.012	.....	.....
			$\frac{S}{t} \times 10^{-6}$	180	80	47	30	20	.....	.....
3	0.360	167	$K_G a$	8.2	6.3	4.8	3.5	2.4	1.6	.....
			$\frac{K_G a}{G^{0.8}}$	0.136	0.105	0.080	0.057	0.037	0.025	.....
			$\frac{S}{t} \times 10^{-6}$	180	80	47	30	20	14	.....
4	0.360	223	$K_G a$	10.2	7.8	5.9	4.3	2.9	2.1	.....
			$\frac{K_G a}{G^{0.8}}$	0.134	0.103	0.078	0.057	0.038	0.028	.....
			$\frac{S}{t} \times 10^{-6}$	180	80	47	30	20	14	.....
5	0.360	369	$K_G a$	16.2	12.0	8.8	6.3	4.4	3.2	2.4
			$\frac{K_G a}{G^{0.8}}$	0.143	0.106	0.077	0.055	0.039	0.028	0.021
			$\frac{S}{t} \times 10^{-6}$	180	80	47	30	20	14	9
6	0.360	235	$K_G a$	12.1	9.5	7.5	5.6	4.1	2.8	1.6
			$\frac{K_G a}{G^{0.8}}$	0.153	0.120	0.095	0.071	0.052	0.036	0.020
			$\frac{S}{t} \times 10^{-6}$	180	80	47	30	20	14	9

Table 3.—*Continued*

Test No.	Average limestone particle diameter, in.	Mass velocity of gas, G*		Per cent of limestone reacted						
				10	20	30	40	50	60	70
7	0.660	223	K_Ga	5.6	3.4	2.1	1.4	1.0	.....	.....
			$\frac{K_Ga}{G^{0.8}}$	0.074	0.045	0.028	0.018	0.013	.....	.....
			$\frac{S}{t} \times 10^{-3}$	54	24	14	9	6	.....	.....
8	0.660	223	K_Ga	6.5	3.5	2.2	1.4	.....	.....	.....
			$\frac{K_Ga}{G^{0.8}}$	0.085	0.046	0.029	0.018	.....	.....	.....
			$\frac{S}{t} \times 10^{-3}$	54	24	14	9	.....	.....	.....
9	0.360	228	K_Ga	14.2	11.4	9.1	7.0	5.0	.....	.....
			$\frac{K_Ga}{G^{0.8}}$	0.184	0.147	0.118	0.091	0.065	.....	.....
			$\frac{S}{t} \times 10^{-3}$	180	80	47	30	20	.....	.....
10	0.360	231	K_Ga	14.5	12.7	10.1	7.1	5.1	3.6	2.4
			$\frac{K_Ga}{G^{0.8}}$	0.186	0.163	0.129	0.091	0.065	0.046	0.031
			$\frac{S}{t} \times 10^{-3}$	180	80	47	30	20	14	9
11	0.360	236	K_Ga	13.1	11.8	10.8	.....	.....	.....	.....
			$\frac{K_Ga}{G^{0.8}}$	0.158	0.142	0.130	.....	.....	.....	.....
			$\frac{S}{t} \times 10^{-3}$	180	80	47	.....	.....	.....	.....
12	0.360	230	K_Ga	.....	.....	.....	9.7	8.1	5.8	3.8
			$\frac{K_Ga}{G^{0.8}}$	.....	.....	.....	0.128	0.107	0.077	0.050
			$\frac{S}{t} \times 10^{-3}$	.....	.....	.....	30	20	14	9
13	0.660	230	K_Ga	12.9	9.3	6.4	4.5	3.3	2.3	.....
			$\frac{K_Ga}{G^{0.8}}$	0.165	0.119	0.082	0.057	0.042	0.029	.....
			$\frac{S}{t} \times 10^{-3}$	54	24	14	9	6	4	.....

* In pounds per hour per square foot of cross-sectional area of tower.
† Over-all absorption coefficient in pound-moles of hydrogen fluoride per hour per cubic foot of packed bed per atmosphere log mean partial pressure of hydrogen fluoride.
‡ S is the specific reaction area of limestone in square feet per cubic foot of bed; t is the thickness of fluoride envelope in feet (see Appendix A).

reacted limestone used in the correlation below, the particle size of the $-\frac{1}{4}$-in. + 6-mesh fraction was taken to be the arithmetical average determined from measurements of the three dimensions of each of 168 particles in a randomized sample. Particle size for the other two fractions was determined indirectly by comparing the rates of dissolution of washed samples of limestone in dilute hydrochloric acid, using the method described by Dalla Valle (*1*). The specific-reaction area, square feet per cubic foot of packing, was calculated for the $-\frac{1}{4}$-in. + 6-mesh fraction using the average dimension and assuming that the formula for a sphere would apply; specific-reaction areas for the other two particle sizes were taken to be proportional to rates of dissolution in dilute acid. The average particle sizes and specific-reaction areas calculated in this manner for the three size fractions used are tabulated in the next column.

Nominal size	Average particle size, in.	Specific area, sq.ft./cu.ft. of packed volume
$-\frac{1}{4}$ in. + 6 mesh	0.188	198
$-\frac{1}{2} + \frac{1}{4}$ in.	0.360	100
$-\frac{3}{4} + \frac{1}{2}$ in.	0.660	55

It was found that absorption data obtained with different size fractions could be correlated graphically using a parameter, S/t, where S is the specific-re-

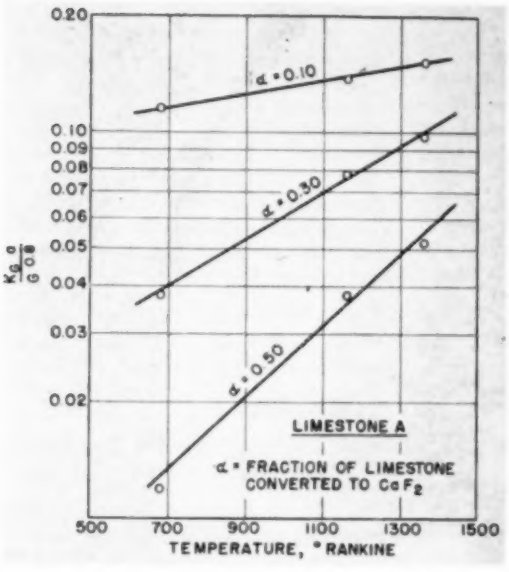


Fig. 5. Effect of temperature on absorption coefficient.

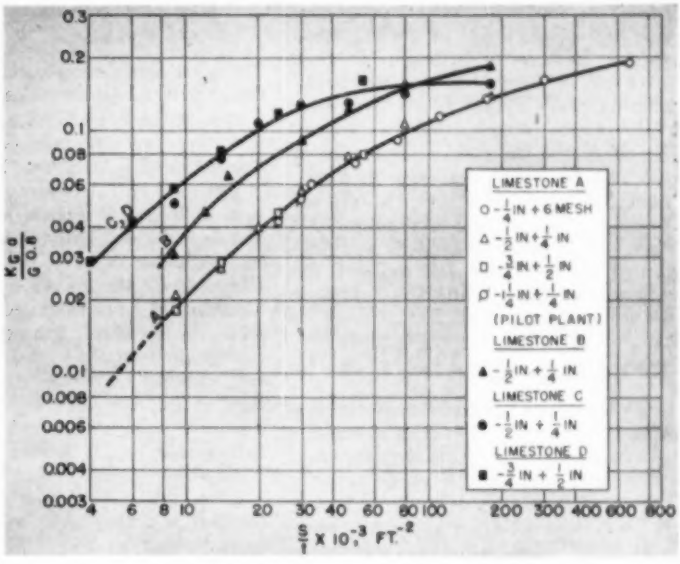


Fig. 6. Absorption characteristics of different limestones.

action area and t is the thickness of fluoride envelope for partially reacted limestone. This parameter, S/t, which depends only upon the particle size and the fraction of limestone reacted, is derived in Appendix A and is given by the equation:

$$\frac{S}{t} = \frac{12(1-f)}{D^2} \frac{(1-a)^{\frac{2}{3}}}{1-(1-a)^{\frac{1}{3}}} \text{ ft.}^{-2}$$

where

f = void fraction of the packing
D = particle diameter
a = fraction of limestone reacted.

The values of $K_G a/G^{0.8}$ and the values of S/t are assembled in Table 3. The plot of $K_G a/G^{0.8}$ calculated from absorption data vs. S/t (Figure 6) shows that for a given limestone and at a given temperature the data for different sizes of limestone particles can be represented adequately by a single plot, curve A in Figure 6.

Absorption Characteristics. Tables 2 and 3 and Figure 6 indicate that the limestones studied absorb hydrogen fluoride at different rates. The absorption efficiencies of the two nonoolitic limestones A and B decrease with the decrease in parameter S/t at a rate appreciably higher than is the case of oolitic limestones C and D. This behavior is attributed to the formation of a more friable envelope of calcium fluoride and subsequent partial sloughing off of this envelope from the oolitic limestones.

The absorption efficiencies of the two similar oolitic limestones, C and D, are approximately the same at equal values of parameter S/t, and the relation between the values of $K_G a/G^{0.8}$ and the parameter is adequately represented by a single curve in Figure 6. Although the chemical composition and structure of the two nonoolitic limestones do not differ appreciably, their absorption efficiencies differ significantly; the reason for this behavior is not clear.

Effect of Hydrogen Fluoride Concentration. In calculating the absorption coefficient,

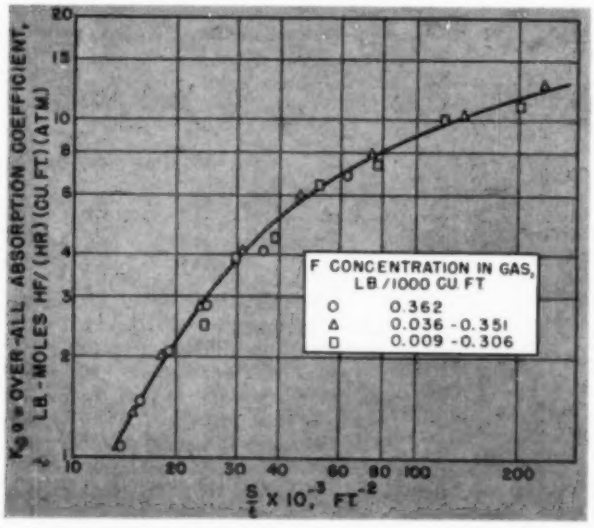


Fig. 7. Effect of fluorine concentration in gas on absorption coefficient.

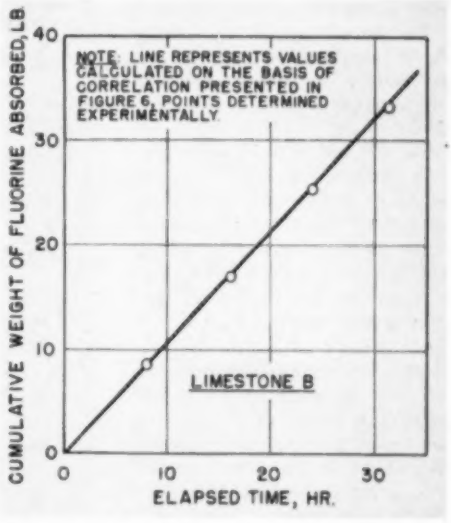

NOTE: LINE REPRESENTS VALUES CALCULATED ON THE BASIS OF CORRELATION PRESENTED IN FIGURE 6, POINTS DETERMINED EXPERIMENTALLY.
LIMESTONE B
CUMULATIVE WEIGHT OF FLUORINE ABSORBED, LB.
ELAPSED TIME, HR.

Fig. 8. Comparison of actual and calculated values for fluorine absorbed in steady-state operation of limestone-packed tower.

it was assumed that the rate of absorption was proportional to the log mean partial pressure of hydrogen fluoride. The validity of this assumption is demonstrated by the plot of the parameter S/t vs. absorption coefficients (Figure 7) calculated for different portions of the bed in which the inlet hydrogen fluoride concentration varied within the limits of 0.362 to 0.009 lb. fluorine/1000 cu.ft. The fact that these data are represented by a single plot supports the assumption used in the calculation of absorption coefficients.

Steady-State Operation of Packed Bed

To determine whether the relationship between absorption coefficients and S/t can be used to predict steady-state operation, a test was made in which partially converted limestone was removed from the bottom of the tower at regular intervals and fresh limestone was added at the top to maintain the volume of the bed. Experimental data for a steady-state period in such a test, in which the packing consisted of $-\frac{1}{4}$- $+\frac{1}{4}$-in. fraction of limestone B, are shown in the following tabulation.

v, cu.ft./min. at N.T.P. 47.9
F concentration, lb. F/1000 cu.ft. 0.413
Temperature of inlet gas, ° F. .....707.

Cumulative time, hr.	Absorption efficiency, %	Cumulative pounds F removed	F content of product, %
8	91.6	8.7	44.6
16	88.5	17.1	43.0
24	89.7	25.6	39.0
31.25	91.7	33.5	39.8
Average	90.4		41.2

Analysis of several portions of the packed bed at the end of the test showed that the fluorine content of the packing varied linearly with bed depth; this observation permits the assumption that during steady-state operation the average fluorine content of the bed is approximately one half of the fluorine content of the partially converted limestone removed from the tower. Using the value of $a = 0.5$, which corresponds to an average fluorine content of 20.6% ($= 41.2/2$), and a void fraction, $f = 0.5$, the parameter S/t is 21×10^3 and the corresponding value of $K_G a/G^{0.8}$ is 0.074, from curve B of Figure 6.

The cumulative weight of fluorine absorbed during the 31.25 hr. of steady-state operation is plotted vs. elapsed time in Figure 8; the straight line represents the predicted rate of fluorine absorption using the foregoing value of $K_G a/G^{0.8}$ and corresponds to the expression

pounds of fluorine absorbed
= $(K_G a)$ (mol. wt. of F) (volume of bed) (partial pressure of HF) (elapsed time)

The agreement demonstrated by the plot shows that the data correlated in Figure 6 can be used to predict steady-state operation for absorption of hydrogen fluoride.

The data in Table 3 and the correlation in Figure 6 can be used also to calculate the depth of packing required to absorb a desired fraction of hydrogen fluoride from the gas, concomitant with a product of given calcium fluoride content. As an illustration, the following calculation determines the depth of packing required to absorb 90% hydrogen fluoride and to make a product containing 90% CaF_2 using limestone of reactivity comparable to that of limestone C. It was assumed that limestone of $-\frac{3}{4}$- $+\frac{1}{2}$-in. size is used, the gas temperature is 700° F., the gas rate is 60 cu.ft./(min.)(sq.ft.) of superficial tower cross-sectional area, and the initial concentration of hydrogen fluoride in the gas is equivalent to 0.5 lb. fluorine/1000 cu.ft. of gas at N.T.P.

From Table 2 the equivalent $CaCO_3$ content of limestone, assuming that MgO also reacts with HF, is

$$\frac{(54.8 + 0.5 \times 56/40)100}{56} = 99.1\%$$

The relation between a, fraction of $CaCO_3$ reacted, and per cent of CaF_2 in the packing is derived as follows, using as a basis 100 lb. packing:

$$CaCO_3 + 2HF \rightarrow CaF_2 + H_2O + CO_2$$

lb. limestone unreacted
$= 0.9 + 99.1(1 - a)$

lb. CaF_2 in packing
$= 78/100 \times 99.1a$

Therefore,

$$\% \ CaF_2 \text{ in packing} = \frac{78/100 \times 99.1a}{0.9 + 99.1(1 - a) + 78/100 \times 99.1a} \times 100 = \frac{7730a}{100 - 21.8a}$$

Since, for this example, the product is to contain 90% CaF_2, the average CaF_2 content of the bed is $\frac{1}{2} \times 90$ or 45%, and the corresponding value of a, obtained by solving the equation

$$45 = \frac{7730a}{100 - 21.8a}, \text{ is } 0.517.$$

The value of the parameter S/t is obtained by substituting the preceding value of a, the diameter of particle in feet, $0.660/12 = 0.055$, and the void fraction f, assumed to be $= 0.5$, into the expression derived in Appendix A:

$$\frac{S}{t} = \frac{12(1 - 0.5)}{(0.055)^2} \times \frac{(1 - 0.517)^{\frac{2}{3}}}{1 - (1 - 0.517)^{\frac{2}{3}}} \text{ ft.}^{-2}$$

$$\frac{S}{t} = 5700 \text{ ft.}^{-2}$$

The value of $K_G a/G^{0.8}$, from curve C in Figure 6 corresponding to $S/t = 5700$ is 0.0385, and the absorption coefficient $K_G a$ is given by

$$K_G a = 0.0385 \times (60 \times 60 \times 0.0805)^{0.8} = 3.619 \text{ lb. mole HF/(hr.)(cu.ft.)(p.p. HF)}$$

For 90% absorption

partial pressure of HF in atmospheres
= (log mean average conc. of HF)

$$\times \frac{1}{19 \times 1000/379} = \frac{0.500 - 0.050}{2.303 \log 0.500/0.050} \times 0.01995 = 0.0039 \text{ atm.}$$

The amount of HF absorbed, lb.-moles/sq.ft. cross-sectional area/hr.

$$= 0.90 \times \frac{60 \times 60}{1000} \times \frac{0.5}{19} = 0.0853$$

$$= K_G a \times \text{p.p. HF} \times L$$

or

$$0.0853 = 3.619 \times 0.0039 \times L$$

from which the required bed depth, L, is computed to be

$$L = \frac{0.0853}{3.619 \times 0.0039} = 6.1 \text{ ft.}$$

Results of similar calculations for different percentages of fluorine removal and products of different fluorine contents are summarized in the tabulation below for limestones of two different reactivities.

Limestone type,	Packing depth, ft.					
	A			C		
% CaF_2 in product	90	80	70	90	80	70
HF removal, %						
90	23.0	17.8	13.8	6.1	5.0	4.3
80	16.1	12.4	9.6	4.2	3.4	2.9
70	12.1	9.3	7.1	3.2	2.7	2.2

The tabulation above also emphasizes the wide range of variation in the reactivity of the different limestones.

Quantitative comparison of the results of this study with the data obtained in the pilot plant (*3*) was made for two tests in which operating procedure was similar. Absorption coefficients calculated from pilot-plant data (limestone A, $-1\frac{1}{4}$ in. $+\frac{1}{4}$ in.) agree with absorption coefficients obtained in the small-scale study. This agreement is

demonstrated in Figure 6, where values of $K_G a/G^{0.8}$ are plotted vs. S/t.

Most of the previously reported data (*3*) were obtained using different limestones; removing partially reacted limestone from the tower periodically; separating a fluorine-rich portion by screening on a 6-mesh screen; recycling the +6-mesh material to the tower; and adding fresh limestone in amounts required to maintain the depth of packing. Absorption coefficients for three such tests, in which an oolitic limestone of high reactivity was used, are compared with absorption coefficients from curve *C* of Figure 6 in the following tabulation. In these tests, steady-state operation was indicated by the fact that the amount of fluorine absorbed from the gas was approximately equal to the fluorine content of the limestone removed from the tower. To derive the values of parameter S/t, it was assumed that the average calcium fluoride content of the bed in pilot-plant tests under conditions of recycling was given by the average of calcium fluoride contents of the partially reacted limestone removed from the tower and of the make-up limestone. This comparison indicates that the absorption coefficients calculated from pilot-plant data are in fair agreement with those that are obtained from the correlation shown in Figure 6 for a limestone of similar structure.

$K_G a/G^{0.8}$	
Pilot-plant tests (3)	Small-scale tests (Fig. 6)
0.054	0.036
0.039	0.028
0.069	0.070

ACKNOWLEDGMENT

The authors express their appreciation to T. P. Hignett, Chief of the Development Branch of the TVA, for his interest and encouragement and to Julius Silverberg for his critical review of the material contained in this paper.

NOTATION

- a = fraction of limestone converted to calcium fluoride
- D = original diameter of limestone particle, ft.
- d = diameter of unreacted limestone core, ft.
- f = fraction of voids in packed bed
- G = mass velocity of gas, lb./(hr.)(sq. ft. of tower cross-sectional area)
- $K_G a$ = over-all absorption coefficient, lb.-moles HF/(hr.)(cu.ft. of bed) (atmosphere of log mean partial pressure of HF)
- L = bed depth, ft.
- N = number of particles of limestone/unit volume of bed
- S = specific reaction area of packing, sq.ft./cu.ft.
- s = surface area of the limestone core for a single particle, sq.ft.
- T = temperature, ° R.
- t = thickness of calcium fluoride envelope, ft.
- V_p = volume of limestone particles/unit of tower volume
- v_p = volume of single limestone particle, cu.ft.
- v_c = volume of unreacted limestone core for a single particle, cu.ft.

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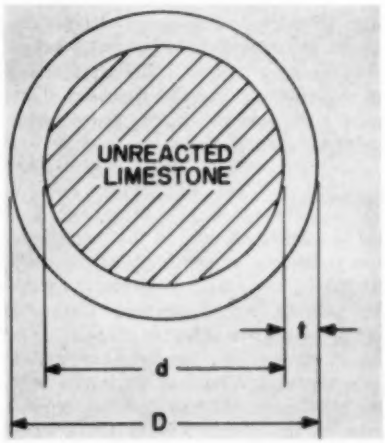
APPENDIX A

Derivation of S/t

The derivation of the parameter S/t is based on the following assumptions:

1. Packing can be treated as an assembly of spherical particles.
2. Reaction of limestone with hydrogen fluoride results in the formation of an envelope of calcium fluoride of uniform thickness, t. The qualitative correctness of this assumption was confirmed by the appearance of partially reacted particles.
3. Specific reaction area is taken as the surface area of the unconverted core of limestone.
4. There is no significant change in the volume of the packing as a result of reaction, an assumption confirmed by experimental observations.

The assumptions above describe the geometrical model shown below in cross section.



Geometrical model of partially reacted particle of limestone.

Reaction area of partially reacted limestone per unit tower volume, S, is by assumption (4) given by

S = (number of particles per unit volume) × (surface area of limestone core)

$$S = N \times s \tag{1}$$

The value of N is derived from geometric considerations as follows:

Volume of each limestone particle,

$$v_p = \frac{1}{6}\pi D^3 \tag{2}$$

Volume of packing per unit tower volume,

$$V_p = 1(1 - f) \tag{3}$$

Therefore, the number of particles per unit volume,

$$N = \frac{V_p}{v_p} = \frac{1 - f}{1/6\,\pi D^3} \tag{4}$$

The surface area of the limestone core,

$$s = \pi d^2 \tag{5}$$

An expression relating t to particle diameter and fraction of limestone reacted is derived as follows:

The volume of limestone core,

$$v_c = \frac{1}{6}\pi d^3 \tag{6}$$

from geometry, and

$$v_c = (1 - a)v_p \tag{7}$$

Substituting (2) into (7) and equating (6) and (7), one obtains

$$\frac{1}{6}\pi d^3 = (1 - a)\frac{1}{6}\pi D^3$$

and

$$d = D(1 - a)^{1/3} \tag{8}$$

By use of (8), (5), (4), and (1), the reaction area per unit volume becomes

$$S = \frac{1 - f}{1/6\,\pi D^3} \times \pi\left[D(1 - a)^{1/3}\right]^2$$

$$S = \frac{6(1 - f)}{D}(1 - a)^{2/3} \tag{9}$$

The thickness of the CaF_2 envelope,

$$t = \frac{1}{2}(D - d)$$

Using (8)

$$t = \frac{1}{2}[D - D(1 - a)^{1/3}]$$

$$= \frac{D}{2}[1 - (1 - a)^{1/3}] \tag{10}$$

The parameter S/t is obtained from (9) and (10):

$$\frac{S}{t} = \frac{6(1 - f)}{D}(1 - a)^{2/3} \div \frac{D}{2}[1 - (1 - a)^{1/3}]$$

$$= \frac{12(1 - f)}{D^2} \times \frac{(1 - a)^{2/3}}{1 - (1 - a)^{1/3}} \tag{11}$$

The parameter S/t is expressed in ft.$^{-2}$ when D is given in ft.

Bubble-Plate Efficiencies

G. D. Shilling*, G. H. Beyer†,

Efficiency data are presented for ethanol-water fractionation at one atmosphere for the center plate of a three-plate 18-in-diam. bubble-cap tower containing ten 3-in. caps/plate. Results are shown for 126 runs at reflux ratios of L/V = 1, ¾, ½, ¼, for liquid concentrations from 70 to less than 1.0 mole % ethanol. All runs were conducted at a superficial vapor velocity of 2 ft./sec.; average slot submergence was 0.9 in.

Plots are given showing the variation with liquid composition of: (1) Murphree plate efficiencies, calculated from plate-to-plate liquid samples; (2) Lewis' Case I local efficiencies, calculated from the same liquid samples by a new method independent of Murphree efficiency calculations; (3) point efficiencies calculated from vapor and liquid compositions obtained with special sampling apparatus, including a chimney inside the tower.

Local efficiencies were found to be independent of reflux ratio, and to range from 30 or 45%, for low concentrations of ethanol in the liquid, to a maximum of 85%, for concentrations of 40 to 65 mole % ethanol.

ALTHOUGH bubble-plate efficiencies in ethanol-water fractionation have been the subject of many previous investigations, a few of the particularly noteworthy ones may be taken as illustrative of the recent advances in the understanding of bubble-plate operation and in the techniques useful in its investigation.

In 1934, Carey et al. (*2*) reported for three systems, including ethanol-water, Murphree efficiencies calculated directly from "plate-to-plate" samplings. This procedure represented a considerable improvement over the older practice of determining column efficiencies for a group of plates over which certain conditions now known to affect efficiencies could show considerable variation.

Peavy and Baker (*9*) in 1937, in an investigation of the effects on efficiency of vapor rate, entrainment, and slot submergence, emphasized the difficulty encountered in the generalization of plate-efficiency data as Murphree plate efficiencies (which can exceed 100%).

W. K. Lewis, Jr., (*8*) in 1936, by mathematical analysis of plate operation, showed the quantitative relationships between actual "local efficiencies" and Murphree plate efficiencies for various assumed flow configurations. The systems analyzed by Lewis of interest to this investigation are his "Case I," where the vapors approaching the plate are assumed to be completely mixed, and his "Case III" for an alternate-cross-flow tower in which the vapors rise from plate to plate without mixing. For both these cases Lewis assumed "that the liquid flows across the plate with no mixing whatsoever." As will be shown later, in many ranges of the variables, Case I and Case III plates operating at the same local efficiencies give enrichments differing by no more than a few per cent.

In 1941, Keyes and Byman (*7*), in their investigation of the effects of reflux ratio and ethanol-water concentration on efficiencies, made use of Lewis' derivations to show the probable magnitudes of local efficiencies involved, but in calculating the local efficiencies from Murphree plate efficiencies they were thwarted by the extreme imprecision inherent in the calculations in the low-ethanol range. For low concentrations of ethanol, the $y^{\star} - y$ driving force may decrease to a very small value as the liquid approaches the plate over-flow, which is the point where this difference is evaluated in the Murphree calculation.

This paper presents ethanol-water efficiency data, for various concentrations and reflux ratios, as Murphree plate efficiencies and as local efficiencies (calculated from the same samples of plate entrance and exit liquids but independent of the Murphree calculations). Also presented are "point efficiencies" for the same runs, but calculated using actual vapor samples.

Equipment

The equipment used in this investigation constituted a rectifying column, arranged in the familiar alternate-cross-flow pattern, containing three plates—a test plate, a plate below to condition the vapors approaching the test plate, and a plate above to condition the liquid supplied to the test plate. For the determination of the efficiencies on the middle plate, the following sampling points were provided (see Fig. 1):

x_a, liquid approaching the test plate, sampled behind a 3-in. weir on the entrance side of the test plate,

x_b, liquid leaving the test plate, sampled behind the entrance weir on the plate below,

x_c, liquid at the center of the test plate, sampled from within ⅛ in. of the surface of the plate at a point midway between the two caps in the middle of the second row and directly below a sheet-metal chimney.

y_c, vapor approaching the center of the test plate, drawn from the vapor space just under the center of the test plate,

y_c', vapor leaving the center of the test plate, drawn from a point about 12 in. above the plate inside a sheet-metal chimney 1½ in. x 3 in. x 20 in. mounted on the two caps in the middle of the second row, with the 3-in. dimension at right angles to the direction of liquid flow,*

x_r, liquid in the reflux line.

* Since the caps were 4 in. tall, the bottom of the chimney being even with their tops should have been above the foam level at the low liquid flows employed here.

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Original data, the basis for this article, are on file (Document 3727) with the American Documentation Institute, 1719 N Street, N.W. Washington, D. C. Obtainable by submitting $1.00 for microfilm and $1.00 for photocopies.

in Ethanol-Water Fractionation

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Since there is some doubt as to which dimensions of a bubble plate are important to satisfactory operations, it is necessary that a presentation of efficiency data include apparatus details, many of which may be of little consequence. The following description of the equipment is therefore supplemented by a table of dimensions (Table 1) and a scale drawing of the plate (Fig. 2).

Table 1.—Dimensions of Experimental Bubble Plate.

Column I. D., in.	17¼
Plate spacing, in.	24
Weir height, in.	1¼
length, in.	10
Caps/plate	10
size (diam.), in.	3
centers, in.	4½
Slots/plate	380
width, in.	⅛
length, in.	½
Slot area/tower area	10.1%
Static seal, in.	½

The test plate carried ten 3-in. bubble caps of 1/16-in. pressed steel. Each cap contained 38 slots ⅛ in. wide, with semicircular tops and bottoms, and ½ in. in over-all length. They were mounted on 4½-in. centers, flush with the plate except for a packing washer which gave the caps an effective skirt height of ¼ in.

Special consideration was given to the following construction features which were thought important: In order that all bubble-cap slots have the same submergence, the plates were machine-cut rather than torch-cut and, after being fitted with caps, etc., were mounted individually in the tower and carefully leveled by means of adjusting screws in their tripod supports. Care was exercised that both inlet and outlet weirs were level. Leakage past the plates was cut to a negligible amount by packing asbestos rope between the tower wall and a packing ring tack-welded to the plate (see Fig. 2). Liquid by-passing of the weirs on the plate was prevented by additional packing between the weir ends and the tower wall. In the absence of an adequate "quieting zone" between the last row of caps and the outlet weir (to keep liquid from surging or being splashed over the weir instead of flowing quietly and maintaining the intended slot seal) the test plate was provided with a baffle in front of the exit weir extending from ½ in. above the plate 8 in. upward. Down-flow channels adequate for liquid flows far in excess of those used in this investigation were provided by twin down-spouts of 1¼-in. i.p.s. pipe, sealed at the bottom by the 3-in. weirs provided at the liquid entrance side of each plate.

The actual average slot submergence was estimated from the static seal and the fluid rates encountered, assuming it to be the sum: (static seal) + (one half the slot height) + (liquid head over the weir) + (one half the hydraulic gradient across the plate), as equal to 0.81 to 0.99 in. The variation of this figure is small compared to what would be expected for this range of operating variables in a large fractionator because, for the 18-in. column, the liquid flow was only 0.31 to 2.6 gal./(min.)(ft. of weir), giving weir crests of 0.042 to 0.174 in. and correspondingly small hydraulic gradients across the plate.

It is sometimes considered necessary to blank some of the bubble-cap slots in an experimental unit to coordinate the vapor distribution with the liquid channels on the plate; however, no slots were blanked in this equipment, although a few slots at the ends of the center row of caps were rendered partially ineffective by the nearness of the packing rim to the caps at these points (see Fig. 2). Although no observation ports were installed in the tower, a plate identical to the test plate (but with no chimney) was tested with air and water in a special, open apparatus and appeared to handle both liquid and gas satisfactorily.

The tower (see Fig. 1) was 18 in. in O.D. and its 8-ft. over-all length was divided by the three 24-in.-spaced plates into four 2-ft. sections. The bottom section carried a baffled 4-in. vapor inlet nozzle in the side and a 2½-in. liquid

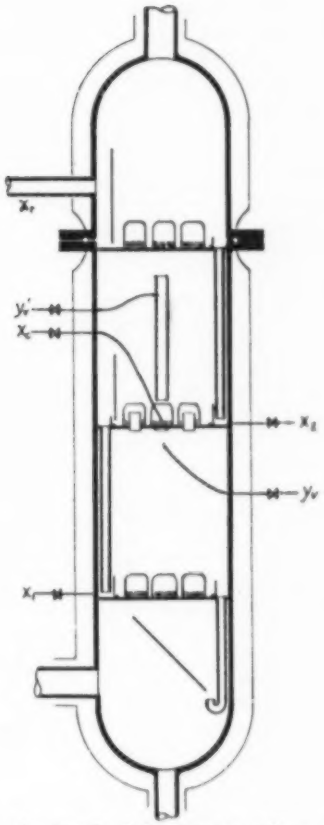
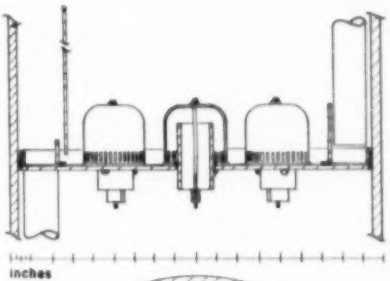


Fig. 1. Detail of fractionating column and sampling lines.



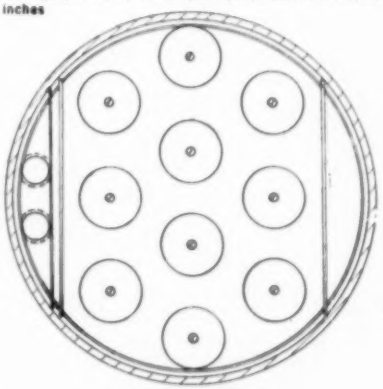


Fig. 2. Detail of bubble tray.

drain at the bottom; the top carried a 4-in. vapor overhead nozzle at the top and a 1½-in. side inlet delivering liquid reflux behind a baffle to the top plate. Four-inch magnesia insulation covered the tower.

The overhead vapors were totally condensed in two parallel *G*-fin heat-exchanger units (see Fig. 3). The condensate-pump discharge divided to pass through two orifice meters: one stream supplied liquid run-back to the top of the tower; the other, constituting the "product" stream during partial-reflux runs, was combined with the liquid overflow from the bottom plate to form the combined feed vaporized in two *G*-fin heat exchangers and charged to the bottom of the tower as boil-up. Thus was simulated a three-plate rectifying column, fed at the bottom with saturated vapors and at the top with liquid reflux, operable at run-back to boil-up ratios of unity or less. Between the reflux orifice meter and the top of the tower, the reflux-liquid stream passed through a steam-jacketed pipe where it was reheated to within a few degrees of its bubble point.

The system distilled was prepared from technical-grade 95% ethanol and water. Analysis of the samples taken from the distillation tower was made against Bureau of Standards density data (*1*) with an inclosed chainomatic Westphal balance. Densities were read to four places (a fifth-place vernier not being used) and temperatures, by a thermometer in the plummet, to 0.3° C. Corrections for inconsistencies among the plummet, index weight, etc., were made from daily checks against purified toluene.

Samples of 30 to 50 cc. were drawn through copper tubes leading to the desired points (see Fig. 1) and passing through baths of circulating lake water used to condense the vapor samples and to supercool the liquid samples. The six samples were drawn nearly simultaneously, after a period of about one hour of undisturbed and apparently steady-state operation. Before a sample was collected, 20 to 30 cc. were withdrawn through the sampling apparatus to flush the lines and rinse the sample bottle.

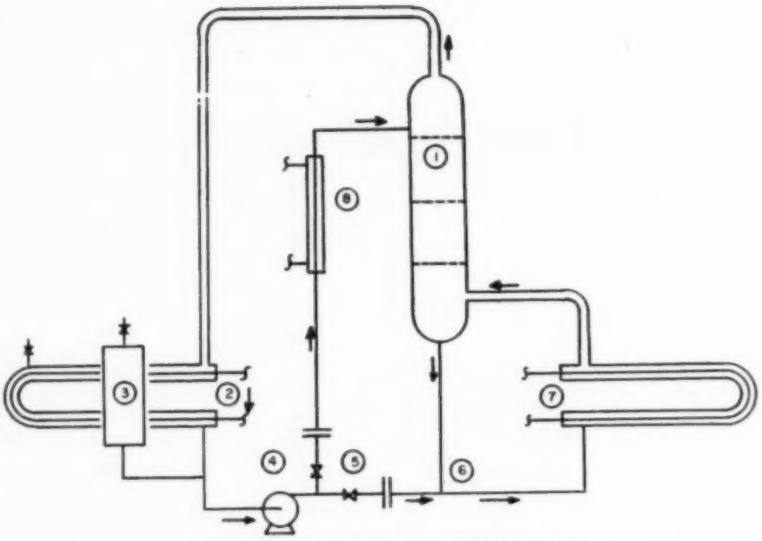


Fig. 3. Flow diagram of experimental equipment

(1) Fractionating column
(2) Condensers
(3) Surge tank
(4) Condensate pump
(5) Valves and orifice meters for reflux control
(6) "Product" mixed with overflow
(7) Vaporizers
(8) Reflux-liquid heater

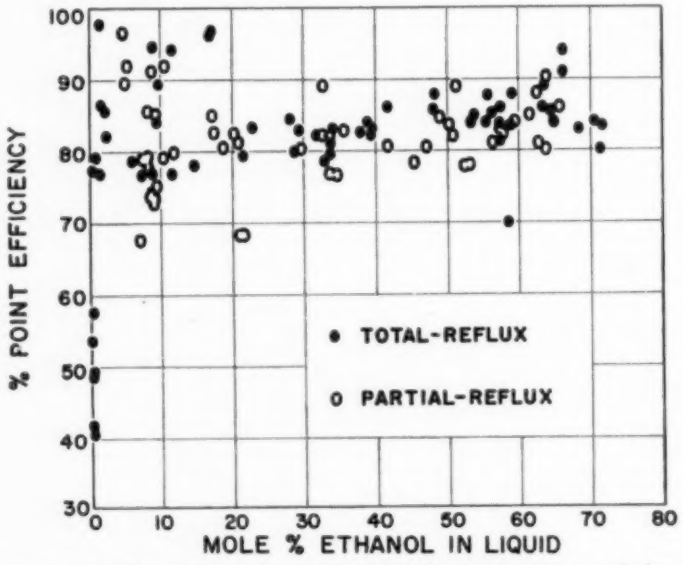


Fig. 4. Point efficiencies from vapor samples vs. liquid composition at center of plate.

Range of Data

Runs were made both at total reflux and at conditions of partial reflux from $L/V = ¼$ to $L/V = ¾$. The pressure on the system was a few inches of water above prevailing atmospheric pressure (normally 740 mm.). In an effort to avoid the effects of distillation rate on efficiency, the runs were made at a single boil-up rate: 24 lb. moles of vapor/hr. This restriction assured a constant linear vapor velocity (2 ft./sec. in the vapor space above the plate) but, of course, did not give constant vapor mass velocity nor constant volumetric liquid flow rate.

The superficial vapor velocity of 2 ft./sec. was chosen as the middle of the range of velocities over which Peavy and Baker (*9*) observed independence of efficiency and vapor velocity, as well as being well below the velocities at which they found appreciable entrainment (at the liquid seal used in this investigation). The Peavy and Baker data on entrainment indicate that the difference between the apparent and "dry" efficiencies would be less than one per cent for a vapor rate of 2 ft./sec., a plate spacing greater than 18 in., and a ½-in. liquid seal.

Since the slot area was 10% of the tower cross section, the vapor velocity in the bubble-cap slots was 20 ft./sec., and accepted formulae indicate that the slots were about fully open at this loading for all ethanol-water concentrations.

To indicate the degree of stability of

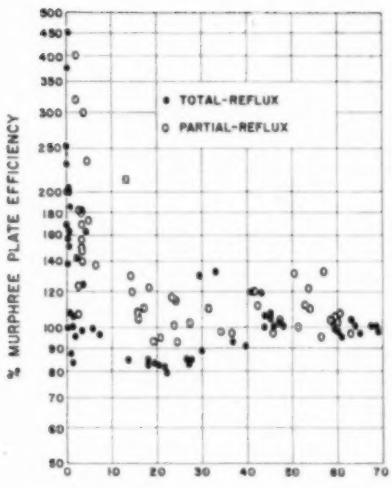


Fig. 5. Murphree plate efficiencies from liquid samples.

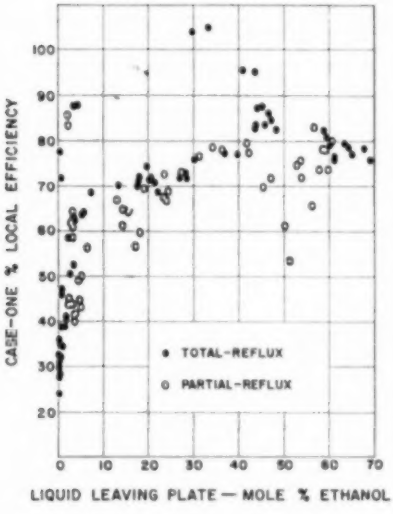


Fig. 6. Local efficiencies from liquid samples.

operation and the probability of the presence of an effectively steady state, each run was made to consist of two, sometimes three, samplings made about one hour apart at the same operating conditions. These *A* and *B* samplings were calculated separately and appear on Figures 4, 5, and 6 as separate points—hence the pairing of points apparent on inspection of these plots. Indications are that effectively steady-state conditions were obtained.

In the eight months during which the data were taken, the average concentration of the liquid on the test plate was varied four times across the range from less than 1% ethanol to above 60 mole %. Minor variations were accomplished by varying the relative amounts of the inventory held in the hot and cold ends of the cycle, while major variations were obtained by changes in the entire charge. Comparison of runs in the same concentration ranges but made at widely separate dates indicated a satisfactory stability of the efficiency-affecting factors.

Calculations

A general value for the accuracy of the efficiencies calculated can not be given. The precision of the concentration values was of the order of 0.1 mole %, which would give excellent accuracy in the $y_2 - y_1$ difference values (some of which were as high as 30 mole %) in all except a few runs at very low ethanol content. In most cases, the accuracy was probably limited by the driving-force evaluation ($y^\star$ minus y, or an equivalent operation), the accuracy of which would be expected to vary widely among the various runs.

The equilibrium data used were those given in the second edition of Perry's Chemical Engineers' Handbook, but little difference would have resulted from use of the more recent data of Jones et al. (*6*). A log-log plot of $y^\star$ vs. x for use in the range below 8 mole % ethanol was constructed from a curve of "activity coefficients" from the equilibrium data. (The curve used extrapolated to $\gamma = 5.20$ for ethanol out of pure water.)

In the calculation of vapor compositions from liquid samples for partial-reflux runs, the Ponchon method was used, with the assumptions that the reheated reflux liquid was saturated and heat losses in the upper half of the tower were negligible (of the order of 1/10% of the heat load on the boiler). The required enthalpy-concentration diagram was prepared from ICT (*5*) thermophysical data. Results of calculations for several of the experimental runs, in which the test plate was severely "pinched" between the operating and the equilibrium lines, were interpreted as evidencing satisfactory consistency among the various data used (thermophysical, equilibrium, and analytical).

Point Efficiencies

From the data of samples x_c, y_v, and y_v', values of the point efficiencies (or local Murphree efficiencies) were calculated for the region of the center of the plate:

$$E_p = \frac{y_v' - y_v}{y_c^\star - y_v} \qquad (1)$$

where y_v is the composition of the vapor sampled under the center of the test plate (see Fig. 1), y_v' is the vapor in the chimney above the center of the plate, and $y_c^\star$ is the equilibrium composition for the liquid sample x_c drawn from the center of the plate. These point efficiencies are plotted on Figure 4.

Murphree Plate Efficiencies

Liquid samples x_1, x_2, and x_r established the average compositions of the vapors approaching and leaving the plate (by equivalence of y_1 and y_2 to x_1 and x_2 at total reflux, and through Ponchon calculations for runs at partial reflux). These values together with equilibrium data permitted calculation of Murphree efficiencies:

$$E_M = \frac{y_2 - y_1}{y_1^\star - y_1} \qquad (2)$$

where y_1 is the average composition of the vapor approaching the plate (calculated from x_1, the liquid leaving the plate), y_2 is the average composition of the vapor leaving the plate (from x_2), and $y_1^\star$ is the equilibrium value for x_1. These Murphree efficiencies are shown in Figure 5.

Local Efficiencies

Local-efficiency values for specific flow configurations can be computed for plates for which entrance and exit concentrations are known. Lewis (*8*) gives for Case I configuration (where the vapors approaching the plate are completely mixed) the equation:

$$\frac{ml'}{L} E_{CI} = \ln\left(\frac{ml'}{L} E_M + 1\right) \qquad (3)$$

where m is a mean value of $dy^\star/dx$, the slope of the equilibrium line.

An alternate method of calculating local efficiencies, directly from x_1 and x_2 values, obviates the evaluation of a mean $dy^\star/dx$. From Equation (1), defining local efficiency, and material balances for differential strips of the plate perpendicular to the direction of liquid flow,

$$E_{CI} = \frac{L}{l'} \int_{x_1}^{x_2} \frac{dx}{y^\star - y_1} \qquad (4)$$

where y_1 is the average composition of the vapors approaching the plate (calculated from x_1) and the integration includes all values of x and its equilibrium function, $y^\star$, between x_1 and x_2. The local efficiency thus calculated is, of course, a mean value for the range of concentrations encountered on the plate. Graphical integration of a plot of $1/(y^\star - y_1)$ vs. x, from x_1 to x_2, is indicated. For cases of constant $dy^\star/dx$ (a straight equilibrium line), Equation (4) reduces to Equation (3). It will be noted that evaluation of E_{CI} by Equation (4) has greater inherent precision than by Equations (2) and (3), since

the "driving force," $y^\star - y_1$, in Equation (4) is integrated over a series of values, whereas in Equation (2) only the smallest, $y_1^\star - y_1$, is used. For example, in Run 80A ($x_1 = 4.9$, $x_2 = 14.7$, $L/V = 0.48$), $y_1^\star - y_1$ was 2.7, but $y^\star - y_1$ increased to 20.5 at x_2 and had an effective mean for Equation (4) of 10.5.

Case I local efficiencies plotted in Figure 6 were computed from x_1 and x_2 values (same samples as for Fig. 5, but independent of Fig. 4) by a modification of Equation (4) permitting use of a single calculation graph for all runs (rather than a separate graphical integration for each set of x limits):

$$E_{CI} = \frac{\dfrac{L}{V}\displaystyle\int_1^2 \frac{dx}{y^\star}}{1 - y_1\left(\dfrac{1}{y^\star}\right)_{avg.}} \qquad (5)$$

The integral $\int_1^2 dx/y^\star$ was evaluated as the difference of two values (for x_1 and x_2) from a large plot of the integral $\int_x^{90} dx/y^\star$ constructed from the $y^\star$ vs. x data for ethanol-water by graphical integration of a plot of $1/y^\star$ vs. x from 90 mole % ethanol to various values of x extending to below 0.1 mole % ethanol (Table 2). The approximation represented by the use of the arithmetic mean of $1/y_1^\star$ and $1/y_2^\star$ was justified when values thus obtained for E_{CI}, in various ranges of the variables, were compared with E_{CI} values from direct graphical integration of Equation (4) (see Table 3).

A further advantage of the "approximate integral" (in addition to time saved) was found in that it does not break down, as do other efficiency calculations, in the case, as of a few low-reflux runs made in this investigation, where the operating line appeared to cross the equilibrium line just *before* reaching x_1 (between x_2 and x_1). Examples are shown in Table 4. Thus, efficiency values calculated by this method, for "pinched" plates, have greater significance than if the Murphree calculation is used (Eq. (2)).

Table 2.—x Mole per cent Ethanol vs. the integral of $dx/y^\star$ from x = 90 to x.

x	$\int_x^{90} \frac{dx}{y^\star}$	x	$\int_x^{90} \frac{dx}{y^\star}$
90	0.000	1.0	1.568
80	0.117	0.8	1.590
70	0.244	0.6	1.618
60	0.382	0.4	1.656
50	0.531	0.2	1.720
40	0.690		
30	0.859	0.10	1.781
20	1.040	0.08	1.801
		0.06	1.826
18	1.078	0.04	1.861
16	1.118	0.02	1.921
14	1.158		
12	1.200	0.010	1.981
10	1.244	0.008	2.001
8	1.290	0.006	2.026
6	1.343	0.004	2.061
4	1.406	0.002	2.121
2	1.494	0.001	2.181

Table 3.—Comparison of Approximate-integral Calculations with Exact Graphical Integration.

Run	L/V	x_1	x_2	E_{CI} by approx.	E_{CI} by exact
60A	1.00	1.5	15	40.8	40.2 ± 0.3
33B	0.25	18	32	59.5	57.5 ± 1.5
31A	0.75	34	56	78.4	78.8 ± 0.3
66A	1.00	69	75	75.8	77.7 ± 1.3

Table 4.—Comparison of E_M with E_{CI} by Approximate Integral for Three Unusual Runs.

Run	80A	80B	80C
L/V	0.48	0.45	0.45
x_1	4.9	3.8	3.5
$y^\star_1$	31.8	27.2	26.1
y_1	29.1	27.6	26.8
x_2	14.7	9.6	8.5
$y^\star_2$	49.6	43.5	41.6
y_2	33.8	30.2	28.9
E_M	174	∞	∞
E_{CI}	44.6	41.3	39.8

Table 5.—Comparable Ethanol-Water Investigations.

Source	Carey	Peavy	Walter	Keyes				Reported here
Lit. Cited	(2)	(9)	(11)	(7)				
Tower diam., in.	6	18	2	5 x 9				18
Plate spacing, in.	10	12	13	11				24
Caps/plate	one	10	part of one	one				10
Cap diam., in.	2.38	3	2	3				3
Slot width, in.	1/8	1/8	3/32	1/8				1/8
Slot area/tower area	3.5%	9.4%	10%	11.4%				10.1%
Static seal, in.	0.5	0.5	0.75	1.2				0.5
Superficial vapor velocity, ft./sec.	0.21	2.0	1-2	1.8		2.2		2.0
Reflux ratio (L/V)	1.0	1.0	1.0	1.0		0.7		
x_1, mole % EtOH	27-34	13-38	30-36	37	72	43	70	
E_M, %	87	89	88-91	97	84	93	81	

Results

A comparison of the data can be made with the results of earlier investigations of ethanol-water fractionation by comparing the values collected in Table 5 with the points on Figure 5 for the same concentration ranges. It is interesting to note how favorably the data of Walter and Sherwood (*11*) compare, in spite of the smallness of their bubble tray.

The degree of reproducibility of the calculated efficiency values can be inferred from inspection of the plots (Figs. 4, 5, and 6): Both E_M and E_{CI} for total-reflux runs of x_1 above 10 show fair consistency among different runs and between A and B sections of the same runs. In the low-ethanol range, E_{CI} is seen to be more reproducible than E_M, as expected in view of the "pinching" in this range where $dy^\star/dx$ is very high. The partial-reflux points in Figures 5 and 6 scatter considerably, because the much lower values of $(y^\star - y_1)$ at low reflux magnify any inconsistencies between Ponchon calculations and equilibrium data. The effect of this lower difference value is not so great in Figure 4, where E_p values were calculated from directly measured vapor compositions.

All runs made during the period April to November, 1949, are represented on Figure 6, except one run (of two parts) at a boil-up rate of 12 lb. moles/hr. (all other runs were made at 24) which gave E_{CI} of 70.5 and 72.8% at an x_1 of 61. Figure 5 does not show four runs of E_M higher than 500% and two at low reflux, for which $(y_1^\star - y_1)$ was calculated to be negative. Figure 4 does not show one E_p of 123% at $x_c = 4$, two other very high values at $x_c = 5$, and two at $x_c = 8$ of $E_p = 7$ and 8%.

Ten points of Figure 6, representing four runs at total reflux and one at partial reflux, will be seen to be obviously in error although the A and B parts of each check fairly well. Perhaps some semistable state of maloperation caused contamination of one or both of the liquid samples x_1 and x_2. E_p values calculated for these same runs from samples x_c, y_c, and y_c' appear on Figure 4, but only one ($x_c = 58$, $E_p = 70$) shows any abnormality.

Comment

Figure 4 shows a definite independence of E_p and reflux ratio and a tendency toward lower efficiencies at lower ethanol concentrations. In the low-ethanol range, together with outright scattering of many of the points, there is an apparent conflict between a sharp drop in efficiency (indicated by a majority of the runs for which x_r was less than one per cent and by the runs for $L/V = 3/4$ at $x_c = 8$ to 9) and a continued gradual decrease to an E_p value of about 78% for the very dilute range. The poor reproducibility in this range of rapidly changing y^* (i.e., below $x = 20$) is not surprising, in view of the dependence of E_p on point samplings of both vapor and liquid; small variations in the positions of the sampling tubes or in the flow patterns of the fluids could effect important changes in the apparent magnitudes of the $(y_c^* - y_v)$ quantity.

Figures 5 and 6, on the contrary, depend only on the two samples of liquid, x_1 and x_2, which were drawn from streams of well-mixed, composited flow. In Figure 5 will be seen a definite tendency toward higher E_M at partial reflux ($L/V < 1$) for the same composition ranges. This trend is predicted by the Lewis equation for Case I (Eq. (3)) if the local efficiency (E_{OI}) is assumed independent of L/V. A similar effect but somewhat smaller is predicted for Case III flow (where the vapors rise from plate to plate without mixing, liquid moving in alternate cross flow). The effect of concentration, as shown best by the total-reflux runs, for which the precision of calculation was greatest, is to give a maximum E_M at about $x = 20$, and approximately constant E_M above $x = 40$. Below $x = 5$, the slope dy^*/dx is so great as to make E_M calculations impractical; the values appear to average 200 per cent for the very low concentrations, but the calculation precision here is very low.

In Figure 6, E_{OI} is seen to pass through a maximum (as reported by Keyes and Byman). The decrease is gradual on either side except below $x_1 = 5$, where there is a rapid decrease to values of 24 to 35% for very low concentrations of ethanol. This sharp drop corresponds so closely to the rapid increase in dy^*/dx that a dependence is almost obvious. And a low transfer rate here is called for by the familiar two-film relationship:

$$1/K_{OG}A = 1/k_GA + m/k_LA \quad (6)$$

which has been shown to apply to bubble plates (*3*). Here if A, the interfacial area, is assumed independent of concentration, the transfer rate is seen to decrease as m (the slope dy^*/dx) increases, unless the conductivity of the liquid film is relatively very high. Of course A for this system may be affected by the increase in surface tension with decreasing x, which is appreciable between $x = 30$ and $x = 0$ mole % ethanol, or the variation in liquid viscosity which reaches a maximum at 30 mole % ethanol—or by any of several other variables.

A slight variation of E_{OI} with L/V in some ranges of Figure 6 may appear to contradict the conclusions drawn from Figure 4 that local efficiencies are independent of reflux ratio, since E_p and E_{OI} are theoretically the same thing (local or point efficiency)—measured here by independent means and using different assumptions (as Case I flow for E_{OI}, and for E_p the difficult "point" samples). However, it should be observed that the concentration of the liquid leaving the plate will be an index of the composition range for an entire plate only for a single reflux ratio. (At a higher L/V, the greater enrichment would result in a lower x_1 for the same inlet concentration to the plate.) So on a plot of E_{OI} vs. x_1 the points for runs at different reflux ratios may be different because of the differences in the plate compositions represented.

Since Case I assumptions are inherent in Figure 6 values, whereas vapor channelling might have made the actual conditions nearer to Case III (a more difficult case to calculate) and liquid mixing may have favored equality of E_M to the true local efficiency, the magnitude of the local efficiencies is left in some doubt. However, E_M values were too often greater than 100% to have approximated the local values; and calculations using Case III assumptions would not have given appreciably different results, as shown in Table 6, where calculations of the local efficiencies by the Lewis equations (*8*) for the two cases are shown for combinations of the limits encountered in the variables.

Table 6.—Per Cent Local Efficiencies Calculated from Murphree Plate Efficiencies by Lewis' Equations for Case I and Case III

Ethanol conc.	$\frac{dy^*}{dx}$	L/V	$m\frac{V}{L}$	E_M	E_{OI}	E_{OIII}
High	0.5	1	0.5	100	81	83
High	0.5	½	1.0	125	81	85
Medium	1.0	1	1.0	57	45	45.2
Medium	1.0	¼	4.0	120	45	46
Low	10	1	10	321	35	36
Low	10	1	10	30,000	80	84

Conclusions

It was therefore concluded that local (or point) efficiencies are independent of reflux ratio (from Fig. 4) and, for the system ethanol-water, vary with the concentration as shown (at least qualitatively) by a series of points for a single reflux ratio on Figure 6 (e.g., total reflux). That is, the efficiency of contact between liquid and vapor decreases moderately, reflecting changes in the physical properties of the system, on either side of a maximum for plates whose liquid concentrations range from about 40 to 65 mole % ethanol; at low-ethanol concentrations efficiency falls off more rapidly (to a value between 30 and 50 for very low concentrations) because of the rapid increase in the effective resistance of the liquid film as dy^*/dx increases.

Liquid concentrations on the plate (entrance side) as high as 72 mole % ethanol are represented among these data. Although this is far short of the azeotropic composition (89%), the authors doubt if any new information would have been obtained in the range between 72 and 89% (a range where the calculation precision would have been very low); for the physical properties of the system show only gradual variations above 60 mole %.

Acknowledgments

The research reported here was done in the department of chemical engineering, University of Wisconsin, Prof. R. A. Ragatz, chairman, and Prof. O. A. Hougen, director of research. Additional financial assistance was obtained from the Wisconsin Alumni Research Foundation, the University of Wisconsin Engineering Experiment Station, and a Universal Oil Products Fellowship grant. Valuable advice and encouragement were given the authors by Dr. K. M. Watson, Madison, Wis., and Dr. A. P. Colburn of the University of Delaware.

Notation

- A = interfacial area for mass transfer, sq.ft./plate.
- E_{OI} = per cent local vapor efficiency of a Case I plate which would give observed enrichment (sometimes designated E_{OG}).
- E_{OIII} = per cent local vapor efficiency of a Case III plate which would give observed enrichment.
- E_p = per cent vapor efficiency at a point or restricted portion of a plate, calculated by Equation (1).
- E_M = per cent vapor efficiency of a plate, based on liquid leaving plate, calculated by Equation (2).
- K_{OG} = mass-transfer coefficient over both films, based on concentrations in gas phase.
- k_G = mass-transfer coefficient of gas film.
- k_L = mass-transfer coefficient in liquid film.
- L = liquid overflow rate, lb. moles/hr.
- ln = natural logarithm.
- V = vapor boil-up rate, lb. moles/hr.
- m = dy^*/dx, slope of equilibrium line.

x = liquid composition, mole per cent ethanol.

x_1 = mole per cent ethanol in liquid overflow from test plate.

x_2 = mole per cent ethanol in liquid entering test plate.

x_c = mole per cent ethanol in liquid at center of test plate.

y_1 = mole per cent ethanol in vapors approaching test plate, calculated from x_1.

y_2 = mole per cent ethanol in vapors leaving test plate, calculated from x_2.

y_c = mole per cent ethanol in vapor approaching center of test plate.

y'_c = mole per cent ethanol in vapor leaving center of test plate.

y^* = composition of vapor in equilibrium with liquid of composition x, mole per cent ethanol.

y^*_c = equilibrium vapor composition for x_c, mole per cent ethanol.

y^*_1 = equilibrium vapor composition for x_1, mole per cent ethanol.

y^*_2 = equilibrium vapor composition for x_2, mole per cent ethanol.

γ = Raoult's law deviation factor (activity coefficient).

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Discussion

Walter E. Lobo (M. W. Kellogg Co., New York, N. Y.): This paper interests me because I happen to be chairman of the Research Committee of the Institute which is planning to sponsor a coordinated program on the determination of tray efficiency. Some comments, prepared by W. C. Schreiner of the M. W. Kellogg Co., are as follows: "With some modification, the experimental study made by these authors can serve as an excellent model for future investigations of this nature. Some refinement of the technique of measuring point efficiencies appears necessary in order to obtain closer agreement between measured and calculated tray efficiencies. (Incidentally, it would be of value if the authors would include a table comparing measured tray efficiencies and those calculated from measured point efficiencies.) The authors should have sampled the liquid on the plate at several elevations in a vertical line above the sample point used, in order to demonstrate whether a concentration gradient existed from the plate floor to the froth level. At higher liquid and vapor loadings than those used by these investigators where considerable transfer may occur in a spray zone above the caps, the same type of multiple sampling might be necessary for the vapor as well. A thorough attempt to relate point efficiency to tray efficiency also requires multiple sampling in a line (or on planes) parallel to liquid flow.

Fundamentally, a program of relating vapor and liquid properties to tray efficiency must deal with the local or point efficiency. The column designer, however, is most concerned with over-all tower efficiencies. For this reason fractionation should be measured across several trays, as well as across a single tray or at a point.

Workers in this field are confronted with a dilemma: whether to measure over-all tower efficiencies or point efficiencies. The former are more useful for design but apparently can not be correlated soundly with fundamental system properties and tray designs. The latter should be capable of being soundly correlated but are difficult to measure and are not related in a simple way to the over-all tower efficiency.

The conclusion drawn by the authors —that point efficiency is independent of reflux ratio should be limited to the type of tray used and the reflux ratios employed. Without the baffle in front of the downflow weir, and at higher throughputs and, or L/V greater than 1, it is possible that point efficiencies will be affected by the greater differences in liquid holdup which will then exist between operations at different reflux ratios."

J. B. Jones (Du Pont Co., Wilmington, Del.): You show in one of the illustrations that the sample is taken behind the inlet weir to determine the Murphree plate efficiency. In an almost identical setup, by injecting dye onto the plate, I found that there was a considerable recirculation of liquid from the plate back behind the inlet weir. I wonder if the authors were aware of this fact or if they took it into consideration?

G. D. Shilling: I am surprised, but I think the 3-in. weir was high enough, when the sampling was done at the bottom where the downcomer entered the pool, so that perhaps it did not make a lot of difference.

J. B. Jones: Did you make any attempt to measure entrainment, and at what plate-spacing did you operate?

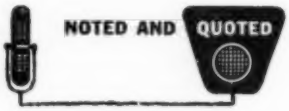
G. D. Shilling: It was a 2-ft. plate spacing. From Peary & Baker's work it would give an entrainment of less than 1%.

J. B. Jones: You added a splash baffle —do the data shown represent conditions with the splash baffle or a mixture of conditions with and without the splash baffle?

G. D. Shilling: All runs were made after the baffle was in place.

J. B. Jones: When you added the splash baffle did you notice any difference in efficiency or pressure drop? Dr. Margaret Hutchinson of Badger Co. has pointed out that the addition of a splash baffle actually increases the effective seal depth which should have some direct effect on the efficiency.

G. D. Shilling: We expected that that would be the case. We didn't measure pressure drops and I am not prepared to say how the efficiencies compared.



It took the Bureau of Reclamation and the contractors about six years to build Davis Dam, not counting the wartime interruption in the work; but it took the architects of law and compromise about fifty years to erect the structure of compacts and understandings which made it possible. . . .

We have just cause to look with pride on what has been done. Hoover Dam and the Lower Colorado development, of which it is the key that opened a new vista of our control of the hydrosphere, were our first large-scale attempt to develop the resources of a major river basin on an integrated basis with an interlocked series of works. At its inception, the plan was properly considered daring—some said foolhardy and reckless. Now, as we finish, we find the physical scope and economic effects of the job to be greater than anyone had contemplated.

—Commissioner of Reclamation Michael W. Straus at the dedication of Davis Dam, Dec. 10, 1952.

Mass Transfer from Benzoic Acid Granules to Water in Fixed and Fluidized Beds at Low Reynolds Numbers

G. C. Evans* and C. F. Gerald†

University of Washington, Seattle, Washington

Mass-transfer coefficients were measured for fixed and fluidized beds of benzoic acid granules dissolving in water. By empirically modifying an application of the Reynolds analogy, the fluidized-bed data were all correlated to a single line with mass velocity the only flow variable; literature data are similarly correlated on parallel lines, with separation due to particle shape differences. The application of the mass-transfer analogy to flow in beds of particles is discussed.

THE rate of mass transfer between solid particles and a flowing liquid is important in many chemical engineering operations, such as leaching, crystallization, and heterogeneously catalyzed reactions, but few investigations of such transfer rates have been reported. In these applications, the solid particles may be disposed in either fixed or fluidized beds, and both schemes have wide utility. Fluidized-bed operation has the major advantages of more uniform exposure of particles to the fluid, due to the mixing action in fluidization, and more ready removal of particles from vessels and their transport, but suffers from the difficulties of particle attrition, erosion, and lack of effective countercurrent operation.

McCune and Wilhelm (*10*) were first to study mass transfer to liquids in fixed and fluidized beds. Using beds of ball-shaped pellets and flat plates of β-naphthol, they measured the rates of solution of the particles in water flowing through the beds under conditions of both fixed and fluidized-bed operation. Hobson and Thodos (*6*) studied the removal, by diffusion into a flowing water stream, of organic liquids impregnating porous solid particles arranged in a fixed bed. Resnick and White (*11*) studied mass transfer from fluidized beds of naphthalene to gases. Several investigators have measured mass-transfer rates to gases from fixed beds of solid particles.

Except for the data of Resnick and White, and of Hurt (*8*) who also studied the sublimation of naphthalene into gases, fixed-bed transfer rates are correlated by plotting j_D against Reynolds number, D_pG/μ. Plotting the j_D factor for conditions of fluidization by liquids does not give a single curve on this plot, but a series of curves with particle diameter as parameter. Gamson (*3*) has recently been able to correlate mass-transfer rates for spherical particles in both fixed and fluidized beds by introducing the fraction voids into both j_D factor and modified Reynolds number. He plots $j_D/(1-\epsilon)^{0.3}$ *vs.* $D_pG/\mu(1-\epsilon)$; the data of McCune and Wilhelm, and of Hobson and Thodos, at low values of this modified Reynolds number give two separate curves, however. Empirical shape factors, not obviously related to the particle geometry, are needed to correlate nonspherical particles.

The present study of mass transfer of benzoic acid to water extends the data on transfer rates to another system, which is of importance because the divergence of the data of Hurt and of Resnick and White may be because of the particular system they used, naphthalene-gas. The present study is in the range of modified Reynolds number of 1 to 100, in which divergent results are reported in the literature. Data for particles in smaller-size ranges are presented, and the use of irregular granules gives qualitative results on the effect of particle shape.

Experimental

The experimental procedure was to allow distilled water to flow upwards through a bed of close-sized granules of USP benzoic acid. The rate of solution of the benzoic acid was calculated from the acid content of the water leaving the 2-in. diam. column.

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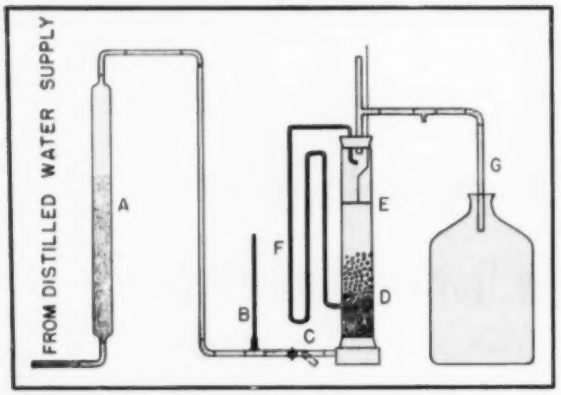
Complete tables of observed and calculated data are of file (Document 3717) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for microfilm and $1.00 for photocopies.



▲ Fig. 1. Schematic layout of equipment.

A—Fluid-bed flowmeter
B—Thermometer
C—By-pass to sewer
D—Bed of benzoic acid granules, above entrance section and screen.
E—Upper screen
F—Manometer
G—Outlet to carboy

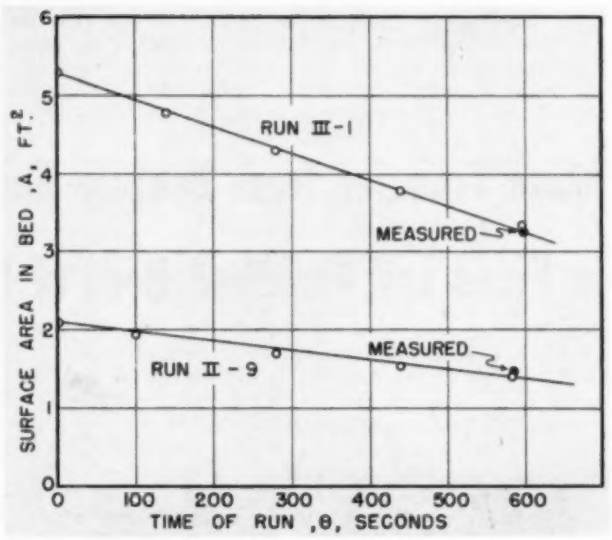


Fig. 2. Changes in particle surface area during run. ►

Surface-area measurements by the permeability method allowed calculation of mass-transfer coefficients.

Apparatus. Figure 1 shows the arrangement of equipment. A tygon-coated drum supplied distilled water to a constant displacement gear pump, which forced the water in succession through a control needle-valve, a fluidized-bed flowmeter (4), the test column, and into a glass carboy. An accurate thermometer in the line just before the test column measured the water temperature. Flow lines and fittings were assembled of glass and tygon tubing of about ½-in. I.D.

The test column was a 20-in. length of 54 mm. pyrex tubing, fitted at each end with rubber stoppers. The flow through the column went upwards through 3 in. of 1/16-in. diam. lead shot, to provide a reproducible entrance velocity front, to the benzoic acid bed. A 40-mesh brass screen just above the lead shot aided further in liquid distribution and separated the test particles from the shot. By means of wire loops attached to the screen the bed of particles could be readily lifted out after an experiment.

A second close-fitting screen was used above the bed of particles to prevent any possible entrainment of particles into the column effluent. The upper screen was fixed to a brass rod that could be moved through a tight-fitting hole in the upper rubber stopper. During fixed bed runs, the upper screen was placed at the top of the particle bed, which allowed operation at higher velocities without bed expansion or fluidization. The pressure drop across the bed was measured between a pressure tap at the lower screen and a pressure tap in the liquid above the bed. Both taps were constructed so their square ends were parallel to the tube axis.

Particles Used. Granules of benzoic acid were prepared by melting USP benzoic acid, allowing it to solidify in large casts, and breaking and grinding the material in a small rotary grinder. The particles were screened on a Ro-Tap shaker. After screening, surface dust was removed and particle wettability improved by rinsing briefly with distilled water, followed by air-drying to constant weight. The smallest-size particles were further separated from some fine material by shaking the dry material on an inclined surface using an action similar to a Wifley table.

The average particle size was determined for each fraction by weighing a counted sample of the fraction, between 1000 and 2000 particles being taken. The particle size reported here is the diameter of an equivolume sphere, which was calculated from the average particle weight and the density of the benzoic acid particles. Particle surface areas were determined by measuring the pressure drop for a measured flow rate of saturated benzoic acid solution through a bed of the particles. The equipment used for this was similar to that of P. C. Carman (2), and his equation relating surface area to pressure drop was used.

The density of the granules was measured by the pycnometer method using saturated benzoic acid solution as the liquid. The value determined was 1.293 g./ml., somewhat above the literature value of 1.266. Saturation values of benzoic acid at various temperatures were taken from the literature, being checked at approximately 25° C. with close agreement. Data of Chang on diffusivity of benzoic acid, as reported by Linton and Sherwood (9) was used to estimate the Schmidt number.

The shape factor of the particles, ϕ, defined as the ratio of surface area of the equivolume sphere to the surface area of the actual particle, varied from 0.50 to 0.65. Table 1 summarizes the data on the four sizes of particles employed.

Analysis of Effluent. Direct titration of the benzoic acid solutions, using 0.04 N sodium hydroxide, to a phenolphthalein end point, was found to give reproducible results. This method was used throughout.

Calculation Methods

Mass-transfer coefficients are ordinarily calculated from the equation:

$$k_F = \frac{W(C_2 - C_1)}{A(\Delta C)_{l.m.}} \qquad (1)$$

This equation is derived assuming a linear change in fluid concentration on passing through the bed, and uniform k_F through the bed. In many of the present runs, the transfer area, which is the total particle surface, A, changed significantly due to solution of the particles (frequently the weight dissolved was 20% of the initial weight, up to a maximum of 56% reduction), hence the proper average area to be used to calculate k_F is of some concern. In order to determine how the particle-surface area in the test column varied during the run, the procedure in several runs was modified; by taking several successive samples of the column effluent, the change in equivalent diameter of the particles could be calculated from the integrated amount of benzoic acid that was dissolved, making the assumption that the total number of particles in the bed remained constant. Using these calculated diameters and assuming that the shape factor changed linearly with time from the initial to final measured values, the particle surface was computed. Two typical sets of data are shown in Figure 2. The general good agreement between calculated and measured final surface areas, in these calculations, confirms the conclusion that the particle surface in the test column varied linearly with time. In general, the measured effluent concentrations were also linear with time. For conditions such as these, one should properly calculate the transfer coefficient by integrating the instantaneous values:

TABLE 1.—PROPERTIES OF BENZOIC ACID PARTICLES

Size No.	Tyler Screen Mesh	Number per Gram	S_o, ft.$^{-1}$	D_p, ft.	Shape Factor, ϕ	Symbol Used in Graphs
I	8-10	156.5	1720	0.00693	0.500	△
II	12-14	545	2480	0.00456	0.531	□
III	20-24	2870	3890	0.00262	0.588	○
IV	24-28	8330	4990	0.00184	0.655	Φ

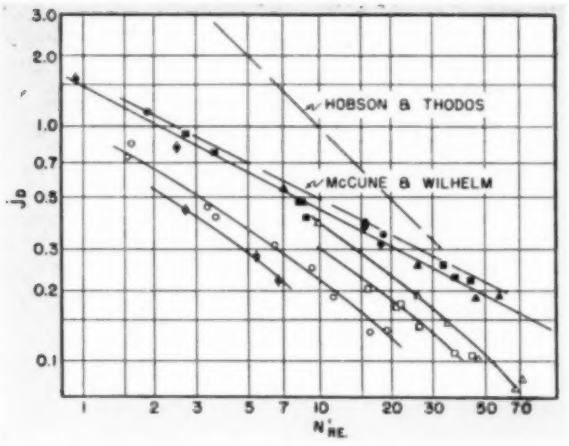


Fig. 3. j factor for fixed and fluidized beds. Solid points are for fixed beds, open points for fluidized beds. (see Table 1 for key to particle size).

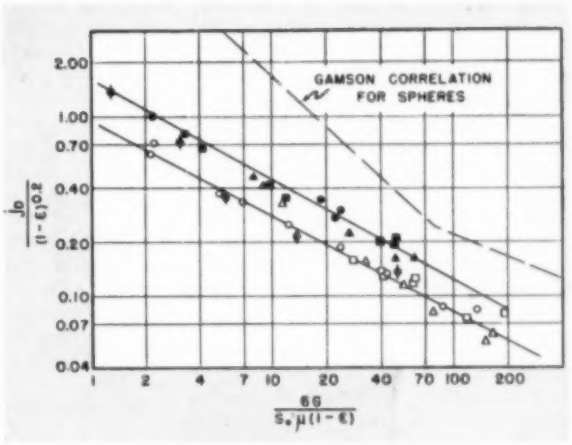


Fig. 4. Comparison with Gamson's correlation for fixed and fluidized bed mass transfer. Solid points are for fixed beds, open points for fluidized beds. (see Table 1 for key to particle size).

Total benzoic acid dissolved during run $= \int_0^\theta k_F A(\Delta C)_m d\theta$

Writing:

$$A = A_1 + b\theta$$
$$(\Delta C)_m = \tfrac{1}{2}[(C^* - C_1) + (C^* - C_2)]$$
$$C_1 = 0$$
$$C_2 = C_1 + b'\theta$$

the integral can be written:

$$\int_0^\theta k_F(A_1 + b\theta)\left(C^* - \frac{C_1 + b'\theta}{2}\right)d\theta$$

$$= k_F\theta\left[\left(A_1 + \frac{b\theta}{2}\right)\left(C^* - \frac{C_1 + \frac{b'\theta}{2}}{2}\right) + \frac{b'b}{24}\theta^2\right] \qquad (2)$$

In the integration, k_F is assumed constant. The arithmetic average concentration difference is essentially the same as the proper logarithmic mean for these runs. The correction term to the product of arithmetic average area and concentration driving force is:

$$\frac{bb'\theta^2}{24} = \frac{1}{24}(A_2 - A_1)(C_2 - C_1) \qquad (3)$$

Since, for the extreme case (56% loss in weight of bed, 46% decrease in area, 30% decrease in effluent concentration), the correction term was only 0.9%, the arithmetic average A and C_2 was used in Equation (1) to calculate k_F.

Figure 3 shows the results as j_D vs. Reynolds number. The average bed height during the fluidized-bed runs, and fraction voids in the fixed-bed tests, based on the average amount of solid present, were employed in the calculations. The mass velocity was determined from the weight of total column effluent per unit time of the run, including samples taken for analysis. A complete tabulation of observed and calculated data (Table 3) are on file with the American Documentation Institute.

Correlation of Results

Fixed Beds. Previous investigators, with the exception of Resnick and White, and of Hurt, have found that, for fixed beds, log j_D is a linear function of the logarithm of the modified Reynolds number for a large range of particle diameters, flow conditions, and system properties. This was also the case in this investigation as shown by Figure 3. The fixed-bed points are all fit by the line

$$j_D = 1.48(N'_{Re})^{-0.52}$$

For the dilute solutions used here,

$$j_D = \frac{k_F}{G}\left(\frac{\mu}{\rho D}\right)^{2/3}$$

This correlation for fixed-bed data is nearly identical with the relation for liquid-phase fixed-bed mass transfer discovered by McCune and Wilhelm for this range of Reynolds numbers, and essentially the same as proposed by Wilke and Hougen (*12*) from gas-phase data. It is in disagreement with the correlation for low Reynolds number proposed by Hobson and Thodos (*7*). The McCune-Wilhelm and Hobson-Thodos correlations for fixed beds are shown as dashed lines in Figure 3.

Fluidized Beds. Under fluidized conditions, plotting j_D against N'_{Re} gives a series of curves with particle diameter as parameter, qualitatively the same as found by McCune and Wilhelm at somewhat higher values of modified Reynolds number. McCune and Wilhelm proposed a general correlation for fluidized-bed transfer coefficients by a plot of j_D against Reynolds number divided by a modified friction factor (*10*). Such a plot appears to bring the data for various particle sizes together, but there is still significant separation of data for various particle sizes. Using the relation that $\Delta p = L(1-\epsilon)(\rho_s - \rho)$, derivable from Wilhelm's work, this general correlation can be shown to be equivalent to a plot of j-factor against the cube of the mass velocity. Any improvement in generality of the correlation compared to the plot of j-factor *vs.* Reynolds number is hence an artificial one.

Gamson's correlation brings the data for fluidized beds all onto the same line, but the fluidized-beds data fall on a different line from the one for fixed beds (see Fig. 4). McCune and Wilhelm's data on nonspherical particles also show this effect, as seen in Figure 5 of Gamson's paper. An effective area shape factor, such as proposed by Gamson, would vary not only with modified Reynolds number, but also with fraction voids if it made all such data fall on the same correlating curve. The difference in slope compared to Gamson's line for spheres emphasizes the difficulties in obtaining a general correlation by this means.

The use of the transfer analogy to relate mass transfer with fluid friction has been most useful in correlation and explanation of mass-transfer rates for flow in tubes and around various shapes. The application of the analogy to flow in beds of particles is not nearly as straightforward because of the unknown effects of curvature of flow, expansion and contraction effects, and ratio of skin friction to total pressure loss. In spite of these complications, the j_D factor and friction factor should be interrelated.

The friction factor in fixed and fluidized beds has been variously defined, however, and the proper definition of friction factor is open to question. A friction-factor definition similar to that of Carman (*1*), based on the particle-

surface area, would seem to have some theoretical justification, because of the importance of surface to skin friction and mass transfer. Carman's friction factor also appears to represent more exactly the actual flow conditions of velocity and hydraulic radius in the bed. However, the curvature of flow- and form-drag effects are less dependent on surface than on particle size and particle separation, measured at least in part by D_p, so that the usual modified friction factor,

$$f' = \frac{g_c D_p \rho \Delta p}{2G^2 L}$$

may alternatively be chosen to express the friction loss. Both relations were tested with the present data.

The "surface basis" friction factor used here (analogous to Carman's friction factor) is derived from the usual modified friction factor, which may be considered as based on particle size, primarily, by substituting G/ϵ for the mass velocity, and four times the average hydraulic radius, $4\epsilon/S_o(1-\epsilon)$, for the diameter term.

Hence:

$$f_s = \frac{g_c \left(\frac{4\epsilon}{S_o(1-\epsilon)} \right) \rho \Delta p}{2 \left(\frac{G}{\epsilon} \right)^2 L}$$

$$= \frac{2 g_c \epsilon^3 \rho \Delta p}{S_o G^2 (1-\epsilon) L}$$

With this surface-basis friction factor, a similarly derived Reynolds number, $6G/\mu S_o(1-\epsilon)$, seems appropriate, and was used. With the modified friction factor, the usual modified Reynolds number, $D_p G/\mu$, was used as correlating variable.

Since, for fluidized beds, the approximate relation holds:

$$\Delta p = L(1-\epsilon)(\rho_s - \rho) \frac{g}{g_c}$$

the modified friction factor can be written:

$$f' = \frac{g D_p \rho (\rho_s - \rho)(1-\epsilon)}{2G^2}$$

and the surface friction factor:

$$f_s = \frac{2\epsilon^3 g \rho (\rho_s - \rho)}{G^2 S_o}$$

These relations are used, rather than measured pressure drops, because of difficulties in getting precise pressure-drop data with short beds.

Figure 5 shows that the plot of the ratio j_D/f_s gives a series of curves, with particle diameter as parameter, that increase to an asymptotic value of about 0.2 as Reynolds number increases. It is significant that this asymptotic value is less than the value of the ratio of j_D to friction factor for turbulent flow in pipes, which is constant at 0.5. The lower values of the ratio with fluidized beds may be indicative of more friction loss expended in viscous shear which is ineffective in aiding mass transfer. When j_D/f_s reaches its asymptotic value, it appears that maximum turbulence has been developed in the fluidized bed; Figure 5 indicates that this is a function of particle size.

When the ratio of j_D to f' was plotted, again a series of curves resulted, with particle diameter as parameter. There was considerably less scatter of the points using this alternative definition of friction factor, however, presumably because the less precisely measured variable, ϵ, does not enter to as high a power. There was less curvature of the lines, also. It was found, empirically, that if $j_D(1-\epsilon)/f'$ was plotted, the lines were straight, as shown in Figure 6.

All the fluidized-bed mass-transfer data are brought together by multiplying the ordinate of Figure 6 by $D_p^{2.6}$. This is demonstrated in Figure 7. The equation for the line through the benzoic acid data is

$$j_D \frac{(1-\epsilon)(D_p)^{2.6}}{f'} = 2.3 \times 10^{-10} (N'_{Re})^{1.33}$$

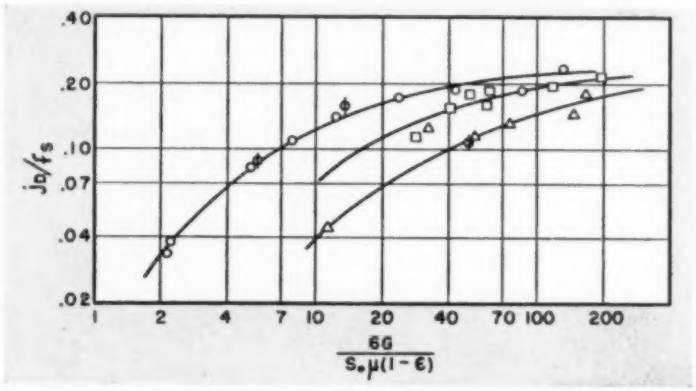


Fig. 5. Ratio of mass-transfer factor to "surface basis" friction factor, as function of surface basis Reynolds number, for fluidized beds.

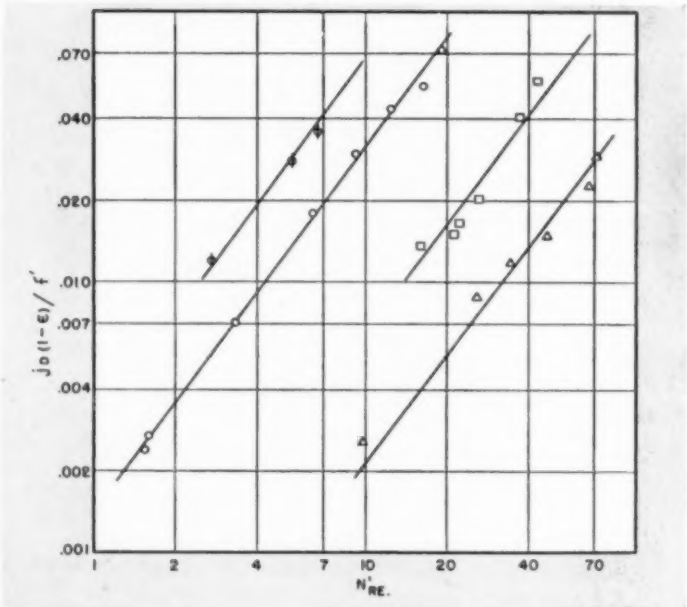


Fig. 6. Empirically modified ratio vs. modified Reynolds number for fluidized beds.

The equation fits the data with a standard deviation of 0.05. The fluidized-bed data of McCune and Wilhelm is also correlated by this function, with the same slope but with shape-factor differences causing a different intercept for the lines. Data of these authors are shown by crosses and solid circles on Figure 7; the present data are indicated by open symbols. Since the shape factor was not constant for the various sizes of particles studied in this work, and because only a few shapes have been studied, quantitative correlation with shape factor is uncertain. It may be observed, however, that data on McCune and Wilhelm's flakes, and for the granules of benzoic acid, are brought to the line for spheres by multiplying the ordinates of Figure 7 by $\phi^{-1.6}$.

Discussion of Results

The correlation of Figure 7, for fluidized-bed transfer to liquids, is especially well suited for design purposes, since the empirically chosen ratio of variables eliminates the appearance of fraction voids in the correlation, and leaves the superficial mass velocity as the sole variable influenced by flow rate. Mass transfer in fluidized beds can hence be predicted from only the fluid and solid properties, and the uncertain prediction of fraction voids is eliminated. From the design standpoint, it is instructive to find the relation between mass-transfer coefficient, k_F, and bed variables. Since, as indicated by Figure 7

$$\frac{j_D(1-\epsilon)D_p^{2.6}}{f'} = 2.3\times10^{-10}(N'_{Re})^{1.33}\frac{2k_FN_{Sc}^{2/3}(1-\epsilon)D_p^{2.6}G^2}{Gg_cD_p\rho(\rho_s-\rho)(1-\epsilon)} = \frac{2.3\times10^{-10}D_p^{1.33}G^{1.33}}{\mu^{1.33}}$$

$$k_F = \frac{1.15\times10^{-10}g_c\rho(\rho_s-\rho)}{\mu^{1.33}N_{Sc}^{2/3}}\frac{G^{0.33}}{D_p^{0.27}} = K\frac{G^{0.33}}{D_p^{0.27}}$$

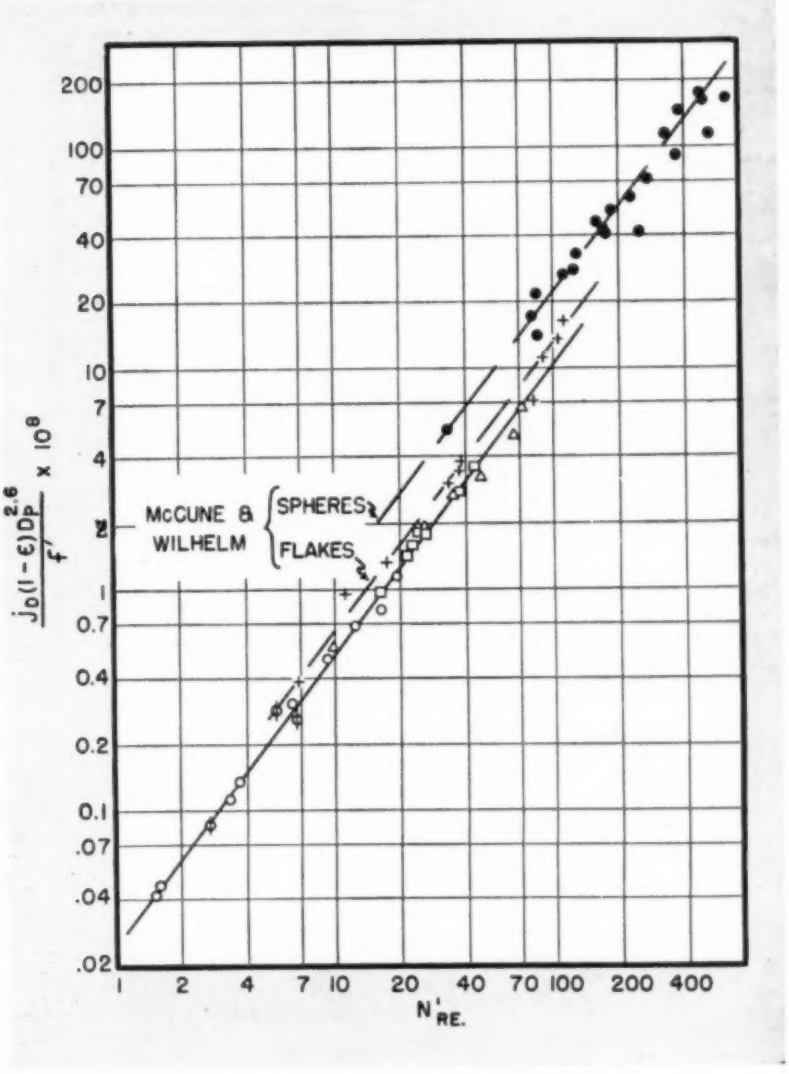


Fig. 7. Generalized correlation for fluidized-bed mass transfer.

Thus, for a given liquid and solid system, the mass-transfer coefficient is indicated to be solely a function of particle size and flow rate. It must be remembered that the dependence of the proportionality factor K on fluid properties has not been investigated experimentally. The relation of K to particle shape is tentatively given as proportional to $\phi^{1.6}$.

The correlation of Figure 5, while less useful for predicting the mass-transfer coefficient, is believed to be of greater theoretical importance. If it is accepted that the surface friction factor does represent true flow conditions in the bed, then the lower value, at higher Reynolds number, of j_D/f_s than the value of the ratio for turbulent flow in pipes can be interpreted to mean that only part of the frictional loss in fluidized beds is effective in promoting mass transfer, *i.e.*, skin friction is only a part of the total friction. It is perhaps not fortuitous that the above-indicated fraction of total friction expended as skin friction is about 40%, while Thom (*5*) has found 43% skin friction in flow around an isolated cylinder at $N_{Re} = 10$.

It is alternatively possible that the observed result is because the bed depth L is less than the effective channel length for the fluid, as indicated by Carman (*1*). If the true path length is of the order of $\sqrt{2}\,L$, as he indicates, the ratio of j_D to a corrected f_s would indicate greater mass transfer than anticipated from the proportion of skin friction around an isolated cylinder. One can rationalize this by noting that form drag, which expends energy in swirls and eddies behind the particle, might increase mass transfer, not on the particle causing the eddies, but on particles downstream from the original particle, due either to mixing action within the

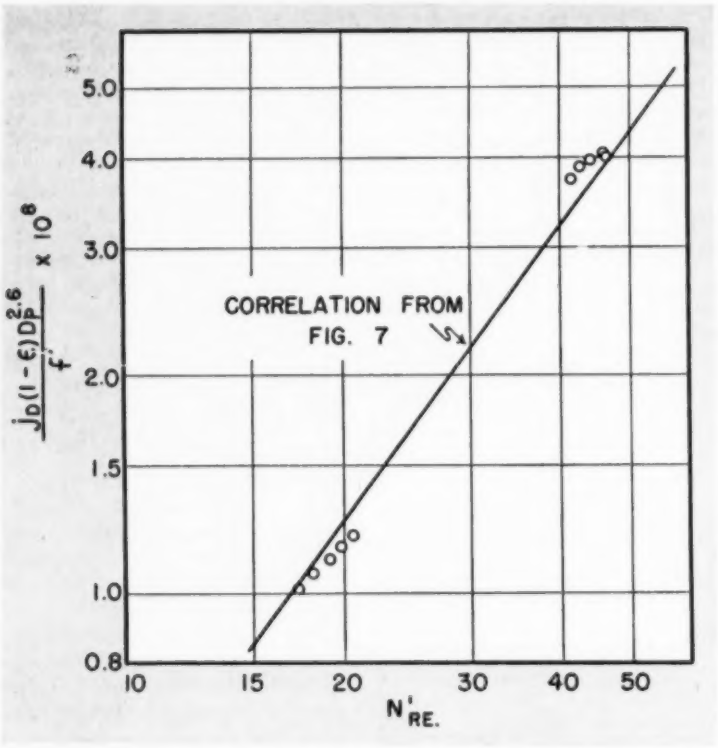


Fig. 8. Comparison of instantaneous values during run with general correlation based on average values.

bulk stream, or by flow-line disruption at the surface of such downstream particles.

Instantaneous Values of Mass-Transfer Coefficient

The fact that particle size changed considerably during these runs means that mass-transfer coefficients and Reynolds numbers also changed. The above correlation, based on average data, if valid, should also apply to instantaneous conditions during the run, although experimental errors would be expected to be larger without the smoothing effect of taking averages. Figure 8 shows, for the same two typical runs which provided data for Figure 2, the agreement of the correlation with the instantaneous data. The data were calculated similarly to the procedure used for Figure 2, discussed above, and is summarized in Table 2. The close agreement of the slope of the curves through the instantaneous points to that for the correlation based on average data is taken as proof that the averaging process used was valid, and the decided change of particle size during the run has not affected the final correlation.

Notation

A = total particle surface in bed, sq.ft.
C = concentration of benzoic acid in water stream, lb./lb.
C^* = concentration of benzoic acid in saturated solution, lb./lb.
D_p = equivalent spherical particle diam., ft.
f' = modified friction factor
f_s = "surface basis" friction factor
g_c = conversion factor for Newton's law
g = acceleration of gravity, ft./(sec.)(sec.)
G = superficial mass velocity, lb./(hr.)(sq.ft.)
j_D = mass-transfer factor
k_F = mass-transfer coefficient, lb./(hr.)(sq.ft.)(unit Δ C.)
L = bed depth, ft.
N'_{Re} = modified Reynolds number, D_pG/μ
N_{Sc} = Schmidt number, $\mu/\rho D$
Δp = pressure drop, lb./sq.ft.
S_o = specific surface, sq.ft./cu.ft. solid
V_o = superficial flow velocity, ft./hr.
W = weight flow rate through bed, lb./hr.
ϵ = fraction voids
μ = fluid viscosity lb./(hr.)(ft.)
ρ = fluid density lb./cu.ft.
ρ_s = solid density lb./cu.ft.
θ = elapsed time during run, sec.
ϕ = particle shape factor

Subscripts:

1—at bed inlet
2—at bed outlet
i—initial value for run
f—final value for run

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TABLE 2.—INSTANTANEOUS OBSERVATIONS DURING RUN

Run	θ	C_2	W	S_o	D_p	A	k_F	N'_{Re}	$j_D \frac{(1-\epsilon)}{f'} D_p^{2.6}$
II 9	0	0.000306	0.0682	2480	0.00456	2.10	22.2	46.4	4.00×10^{-8}
	100	0.000294	0.0646	2440	0.00449	1.95	23.0	46.0	4.04×10^{-8}
	280	0.000271	0.0581	2390	0.00433	1.72	23.9	44.1	3.96×10^{-8}
	440	0.000250	0.0529	2350	0.00420	1.54	24.5	42.8	3.89×10^{-8}
	586	0.000232	0.0485	2330	0.00406	1.41	24.7	41.4	3.72×10^{-8}
	(final measured values)			2380	0.00397	1.43			
III 1	0	0.000924	0.1102	3890	0.00262	5.32	21.7	20.6	1.20×10^{-8}
	140	0.000862	0.0979	3940	0.00252	4.79	22.3	19.8	1.16×10^{-8}
	280	0.000802	0.0864	4010	0.00242	4.30	22.9	19.1	1.11×10^{-8}
	440	0.000735	0.0743	4105	0.00231	3.79	23.6	18.1	1.07×10^{-8}
	595	0.000667	0.0638	4210	0.00219	3.34	24.1	17.3	1.01×10^{-8}
	(final measured values)			4150	0.00222	3.29			

Mass Transfer in a Fluidized Bed

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Mass-transfer data are presented for transfer between regular-shaped solids and a turbulent gas stream for both fixed and fluidized granular beds, and a simple generalized correlation is achieved. In contradiction to two previous investigations on gas-solid fluidized beds, the data are found in agreement with practically all the fixed-bed data of widely varying systems, as well as with data for fluidized liquid-solid beds. The equations for mass transfer can be stated by

$$j_d = 5.7[D_pG/\mu(1-\epsilon)]^{-0.78} \quad 30 > D_pG/\mu(1-\epsilon) > 1$$

$$j = 1.77[D_pG/\mu(1-\epsilon)]^{-0.44} \quad 10{,}000 > [D_pG/\mu(1-\epsilon)] > 30$$

The Chilton-Colburn analogy of mass transfer and pressure drop for flow in conduits is modified for flow in granular beds. The resulting relation holds remarkably well over a wide range of Reynolds and Schmidt numbers, making possible the prediction of mass-transfer data in granular beds from the more easily obtained pressure-drop data. The equation relating mass and momentum transfer can be simply stated by $j_d = f/10$.

THE growing importance of fluidization is attested to by the number of proposed applications for the technique recently made in the literature. These applications involve the mass transfer of gases to or from solid surfaces, so that a quantitative knowledge of the factors that influence the rate of transfer is of importance to fluidized-catalytic-reactor design. This is especially true where the rate of conversion is limited by transfer rates of reactants to the solid surface or of the products of reaction from the surface.

Three previous investigations (*13, 17, 18*) have been made. McCune and Wilhelm (*17*) studied the mass transfer between a solid and the fluidizing water. Resnick *et al.* (*18*) investigated the mass transfer between naphthalene particles and the fluidizing air. The surface area of the particles was determined by the pressure-drop measurements in the fixed bed. The naphthalene particles, however, have a tendency to cake and to channel, giving a pressure drop which may have no relation to the initial total exposed area. Meantime, any small change in the voidage will cause a large change in the pressure drop and hence in the calculated surface area. Moreover, the data had been obtained in such a manner that the concentration of the naphthalene in the exit-gas stream was between 90 and 99% saturated. At the percentages of saturation above 90%, the experimental errors are magnified by a factor of 4 to 17, exclusive of the error in the surface area. This will be further discussed in a later section.

Kettenring *et al.* (*13*) investigated the simultaneous mass and heat transfer of water vapor into air from irregularly shaped alumina and silica gel particles in a 2.3-in. column. The mass-transfer factor was found consistently increasing with Reynolds number in the fluidized bed. When the mass-transfer factor was plotted vs. Reynolds number, as presented in Figure 1, all particle sizes fell on one curve in the fluidized region.

Several assumptions were involved. The effective transfer-surface area was assumed, for instance, to be equal to the ratio of the bed height at the point of saturation to the total bed height multiplied by the total surface area. The total surface area in turn was obtained by assuming that the irregularly shaped particles were equivalent spheres. However, present data taken in a 2-in. column (*11, 12*) indicated that the total pressure drop of the particle in a fluidized bed did not vary linearly with the bed height.

All these previous data on fluidized beds, along with those in the fixed granular region of other investigators (*4, 5, 7, 25*), are shown in Figure 1. The results are plotted as the mass-transfer factor vs. the Reynolds number. The wide discrepancies among the results of the three investigations are noted. Particle size appears as a parameter in the fixed-bed region in the work of Resnick and White (*18*) and Hurt (*8*) (not shown). This effect is absent from the work of the other investigators (*4, 5, 7, 17, 25*). In the fluidized-bed region, the data of Resnick show an effect of particle size, while the data of Kettenring show no such effect. In the results of McCune and Wilhelm (*17*), the particle size appears as a parameter in the fluidized-bed region, as it does in the work

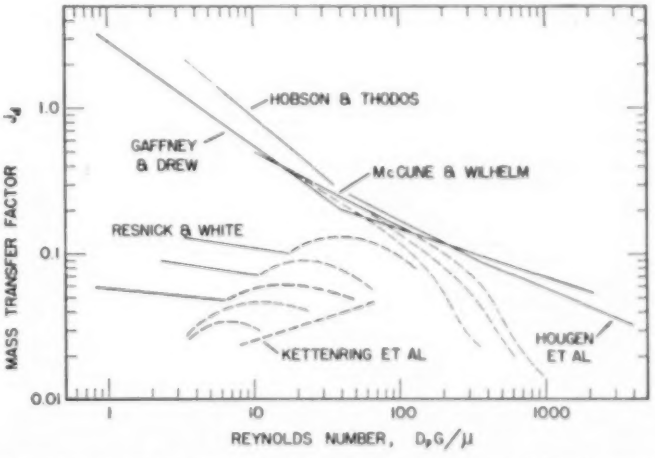

Fig. 1. Comparison of previous mass-transfer investigations in fixed and fluidized granular beds. ——— Fixed bed. – – – – Fluid bed.

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Complete tabulated data may be obtained from American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C., under Document No. 3719; price of microfilm is $1.00, of photocopies $2.70.

of Resnick. The data referred to by the previous investigators, except for those of Resnick and White and Hurt, were correlated by Gamson (*6*).

Another discrepancy is the effect of the nature of the gas. Resnick and White (*18*) observed that the nature of the gas being used as a transfer medium was a parameter. Hobson and Thodos (*7a*) reported that the mass-transfer factor was independent of the gas; they used the same gases as did Resnick and White and also other gases. This work was undertaken with the object of getting reliable and consistent data on mass transfer in both fluidized and fixed beds with the improved experimental method. It is the hope of the authors to clarify much of the present confusion concerning mass transfer in fluidized beds. With pressure drop taken simultaneously, a possible analogy between mass and momentum transfer can be developed.

Materials Used

The system naphthalene air was used because of the small adiabatic temperature drop and its coating properties. The naphthalene was reagent grade from Adamson and Baker. The vapor pressure, as determined on the equipment, and independently in a vapor pressure set-up, checked I.C.T. (*9*) values with an average deviation of +1%. The materials coated were chosen to give as wide a range in density and particle size as was practicable (*see* Table 1). Three sizes of Johns Manville cylindrical Celite catalyst carriers and commercial lead shot were used. The other two particles were rape seed and small glass beads.

Equipment

A flow sheet of the equipment is presented in Figure 2. The fluidizing column (1) consisted of a 4-in. O.D. lucite tube with ⅛-in. wall thickness, and length of 12 in. The screen at the bottom of the column was 200 mesh stainless steel, covered with a fine filter cloth. The top of the column was covered by two cloth filters, between which were sandwiched several layers of glass wool. A pressure tap (10) near the top of the column was used to measure the pressure in the column. Thermometers (5) measured the temperatures of the gas before and after it left the columns, and in some of the later runs the temperature of the gas between columns was measured. The saturator (*2*), placed on top of the fluidizing column, was similar in construction to the latter. It was provided with sufficient naphthalene surface area to ensure saturation of the gases leaving the fluidizing column. The columns were supported on a base, which also housed the dust-collection packing (4) to prevent the entry of dust into the column. The jacket (11) was used as a by-pass for the attainment to equilibrium conditions between the columns and the gas stream before the start of a run. The adsorber (3) contained activated carbon, which prevented the contamination of the laboratory air. The air was metered by means of orifices (6) calibrated in place. Air was supplied by means of a blower (12) blown over water-cooled porcupine-type tubes and dehumidified by means of silica gel in the heat exchanger and drier (13). The runs were started and stopped with quick-opening valves (8) in the main and by-pass lines.

Experimental Procedure

This work was carried out by use of regularly shaped particles coated with the diffusing material, naphthalene, the particle surface being prepared to get good adhesion between the surface and the naphthalene. Celite cylinders were soaked in molten naphthalene and allowed to drain; lead shot was treated with dilute sulfuric acid; glass beads were etched with hydrofluoric acid fumes; and rape seed was cleaned by boiling with acetone. The coating itself was applied by placing the particles in a constantly rotating baffled drum and spraying in molten naphthalene with a compressed-air spray gun. The naphthalene was kept in a molten state by placing the spray gun on a hot plate. This technique was used to prevent caking of particles during the subsequent fluidizing operation. After coating, the particles were sampled, a statistical sample of 100 or more particles being taken. The sample was weighed, and then micrometer measurements were taken on each individual particle of the sample. A charge of the coated particles was placed in the fluidizing column and weighed on an analytical balance. The saturator was also weighed at the same time. The two columns were then bolted together, covered with blank flanges at the open ends, and placed in the column. The blank flange at the end of the column prevented the columns from being seated in the base, but did allow passage of the air from the base into the jacket and around the columns. To facilitate the approach to equilibrium, the air temperature was adjusted as close as possible to room temperature, usually within a degree. Usually ½ to ¾ hr. was allowed for the attainment of equilibrium. To save time in the later runs, a thermometer was placed in the fluidizing column, and when the air temperature and the temperature in the fluidizing column were equal, the run was started. First the air was by-passed from the jacket. The columns were bolted to the base and to the adsorber, and the pressure taps and thermometers were then placed in position. The quick-opening valve to the column was opened, that to the by-pass closed, and the stop-watch started simultaneously. The various manometers needed to establish the velocity and pressure were read, and the thermometer readings in the gas stream, the bed height, and the barometric pressure were recorded. The run was stopped with the quick-opening valve, the stop-watch being punched simultaneously. Both columns were then weighed again to determine the weight loss.

Method of Calculation

Specific Surface. The specific surface was obtained by taking a statistical sample of 100 or more particles and then weighing and taking micrometer measurements on each particle. The surface areas per unit weight were calculated by

(for the cylinders)

$$A_w = \frac{1}{W}\sum_{1}^{N}\left(\frac{\pi}{2}D_c^2 + D_cL\right) \quad (1)$$

(for the spheres)

$$A_w = \frac{1}{W}\sum_{1}^{N}\pi D^2 \quad (2)$$

Equations (1) and (2) were solved by graphical integrations.

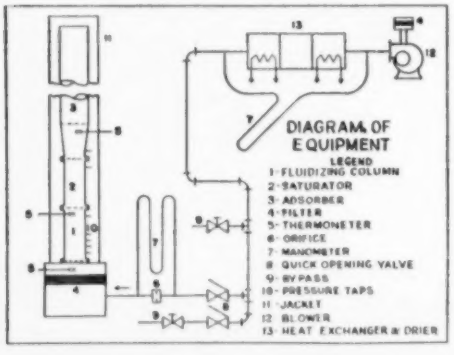
Vapor Pressure. The outlet partial pressure was calculated by means of Dalton's Law, which gave

$$p_g = \frac{M_r\Delta W_c p_b}{V\theta} \quad (3)$$

Since the amount of naphthalene in the air stream was small, the total pressure of the gas stream could be substituted for the partial pressure of the air, so that

$$p_g = \frac{M_r\Delta W_c \pi}{V\theta} \quad (4)$$

This same formula was also used to obtain the out-vapor pressure of the gases from the saturator, except that W_c was replaced by the sum of the loss in weights of both the fluidizing column



◄ Fig. 2. Diagram of equipment.

TABLE 1.—DESCRIPTION OF FLUIDIZED PARTICLES

Particles	Particle diameter, in.			
Celite cylinder				
Large	0.532;	0.554		
Medium	0.330;	0.338		
Small	0.2075;	0.2215		
Lead shot				
Large	0.735 ;	0.0772;	0.0792;	0.0819
Medium	0.0492;	0.0504		
Small	0.0275;	0.0301;	0.0302	
Rape seed	0.0786			
Glass beads	0.0286;	0.029;	0.0273	

and the saturator. Equation (4) then became

$$p_g = \frac{M_r}{V\theta}(\Delta W_c + \Delta W_s)\pi \quad (4a)$$

From Equation (4a) it is seen that, if any errors were made in the run time θ, in the air velocity V, or in the weighing of the saturator and the fluidizing column, they would be reflected in the calculated value of the partial pressure of the gases leaving the saturator. Since sufficient surface area was provided to ensure saturation of the gases leaving the saturator, the partial pressure should equal the vapor pressure. Comparison of the I.C.T. value of the vapor pressure at the observed temperature with that calculated from Equation (4a) provided a check on the accuracy of the recorded data.

The vapor pressure so obtained usually checked within 5% of the I.C.T. vapor pressure corresponding to the outlet-gas temperature. The lowering of the surface temperature because of adiabatic evaporation was small, being of the order of 0.1 to 0.3° C. This was determined experimentally by packing both columns with naphthalene and allowing the gas stream through both columns to come to equilibrium with the naphthalene. When equilibrium was reached, the inlet- and the outlet-gas temperatures were recorded. Since sufficient surface was present so that the outlet-gas stream was saturated, the outlet-gas temperature and the surface temperature of the solids were equal. The experimentally determined surface temperature and the inlet-gas temperature can be related by

$$(t_{gi} - t_s) = 2.53\, p_s \quad (5)$$

The vapor pressure of solid naphthalene is given by the following equation from the I.C.T. (*9*) for the range of 0° to 80° C.:

$$\log p_s = -\frac{3729.3}{T_s} + 11.450 \quad (6)$$

Substitution of Equation (6) in (5) will give the surface temperature in terms of the inlet-gas temperature. In actual practice, both equations, (5) and (6), were plotted to give adiabatic cooling lines, such as are given on any humidification chart. Even if the gas does not come out saturated, the solution of Equations (5) and (6) will give the surface temperature (*23*).

Mass-transfer Coefficient. The mass-transfer coefficient was calculated by means of

$$k_g = \Delta W_c / M_a A \theta \Delta p_{lm}$$

The equation shown above for k_g was derived for the case of the inlet gas entering the column free of the diffusing component; constant solids temperature; and no variation of the mass-transfer coefficient with bed height.

Mass-transfer Factor. The following equation, suggested by Chilton and Colburn (*3*), is the most convenient form to correlate the mass-transfer data:

$$j_d = \frac{K_g p_{bm} (N_{Sc})^{2/3}}{G_m} \quad (7)$$

Substitution of Equations (3) and (6) in Equation (7) gives

$$j_d = (S/A)\, \ln\left(1 - \frac{p_g}{p_s}\right)^{-1} (N_{Sc})^{2/3} \quad (8)$$

Two methods were used to evaluate the ratio of the partial pressure of naphthalene in the exit-gas stream to the partial pressure or vapor pressure at the solids surface, p_g/p_s. In the first method, Equation (4) was used to determine the outlet partial pressure. To evaluate the vapor pressure of the surface, it is necessary first to obtain the surface temperature by Equation (5), as previously explained. Equation (6) is then applied to get the vapor pressure at the surface, p_s.

In the second method of calculation, the ratio of the partial pressures is obtained by using a ratio of the loss of weights of the two columns. Equation (4) is used as in the first method to get the outlet partial pressure of the gases out of the fluidizing column. Instead of the temperature of the surface, Equation (4) is used to get the vapor pressure. Substitution of Equation (4) into (8) gives

$$j_d = (S/A)(N_{Sc})^{2/3} \ln\left[1 - \frac{\Delta W_c \pi_c}{\pi_s(\Delta W_c + \Delta W_s)}\right]^{-1} \quad (9)$$

In those cases where there was a small temperature difference between the calculated surface temperature and the temperature of the outlet-gas stream leaving the saturator, Equation (6) was used to calculate what the vapor pressure would have been if no difference had existed. The vapor pressure of the gases leaving the saturator p_s' and that of the naphthalene at the surface in the fluidizing column p_s are related to their respective temperatures by rearranging Equation (7) as follows:

$$p_s'/p_s = 10^{A(1/T_s' - 1/T_s)} \quad (10)$$

Assuming that the product of the two temperatures $(T_s)(T_s')$ is approximately T_s^2, Equation (10) becomes:

$$p_s = p_s' 10^{A\Delta T/T_s^2} \quad (11)$$

where ΔT = temperature difference between the surface temperature in the fluidizing column and the saturator outlet-gas temperature.

Substituting Equations (11) and (4) into Equation (8), one obtains

$$j_d = \frac{S}{A}(N_{Sc})^{2/3} \ln\left[1 - \frac{\Delta W_c}{(\Delta W_c + \Delta W_s)} \frac{\pi_c}{\pi_s}(10^{A\Delta T/T_s^2})\right]^{-1} \quad (12)$$

The correction term $(10^{A\Delta T/T_s^2})$ was usually small, varying between 0.98 and 1.02.

Both methods of calculation yielded substantially the same results, as seen in Table 2. The values differed by a root-mean-square deviation of 6%, the maximum deviation being 13%. Only the results calculated by the first method were used in the graphs presented.

To calculate the Schmidt number, the viscosity and density of air were used for the mixture of naphthalene and air, since the concentration of naphthalene alone in the film is negligible compared to the air. The diffusivity D_v was taken from the I.C.T. (*10*) for naphthalene air. The Schmidt number does not change appreciably with temperature (*19*), and its constant value of 2.57 at 0° C. was used for all the runs.

Voidage. The voidage, the free fractional volume, is defined as

$$\epsilon = 1 - \frac{\text{volume occupied by the solids only}}{\text{total bed volume}} \quad (13)$$

The volume occupied by the solids was obtained from the geometry of the solids, and the total volume from the bed height and cross-sectional area of the column. For the case where the bed height was below ½ in., the voidage curves (*11*) for the particles obtained from higher bed heights was used. This was necessary owing to the difficulty of reading very small bed heights.

Experimental Results

Table 2 is a sample tabulation giving a description of the particles, the experimental data, and the calculated results.* Figure 3 shows the results of the mass-transfer factor j_d vs. Reynolds number of the various naphthalene-coated particles in both fixed and fluidized beds. For the smaller particles, no data were taken in the fixed bed. The smaller particles required the use of very small bed heights to prevent the exit gases from the fluidizing column from becoming over 90% saturated. This was necessary to reduce experimental error in the final calculations, as discussed later.

* See note, p. 141.

TABLE 2.—SAMPLE TABLE OF SUMMARIZED MASS-TRANSFER DATA ON NAPHTHALENE

Run	108	109	113	135	137	60	62	67	147
Particle description	Large Celite cylinders					Small Celite cylinders			
State of bed	Fixed	Fluid	Fluid	Fixed	Fluid	Fixed	Fixed	Fluid	Fluid
Part. diam., in.	0.532	0.532	0.532	0.554	0.554	0.2075	0.2075	0.2075	0.2215
Vel., lb./hr. air	92.0	158	309	30.0	188	35.8	61.5	320	78.3
PP gas out, mm. Hg	0.0298	0.01812	0.01217	0.0212	0.0106	0.0558	0.0598	0.01678	0.0209
Surf. temp., °C.	20.96	22.74	21.11	19.77	21.70	25.3	26.75	24.24	19.36
Col. wt. loss, g.	0.415	0.260	0.159	0.283	0.269	1.296	2.382	1.151	0.365
Surf. area, sq.ft.	1.332	0.821	0.897	0.631	0.633	1.148	1.145	1.162	0.760
Time, min.	3.55	2.188	1.00	10.04	3.23	15.00	15.00	5.0	5.255
k_g, lb. mole/(hr.)(sq.ft.)(atm.)	1.61	1.877	2.60	0.863	1.778	1.078	1.59	2.162	1.840
jd (1st method)	0.0751	0.0525	0.0364	0.1188	0.0415	0.1278	0.110	0.0289	0.1015
Bed ht., in.	2.0	1.25	3.0	1.0	1.3	0.5	0.5	2.0–3.0	0.6
Total wt. loss, g.	0.912	1.085	.....	0.725	1.654	2.064	4.181	.....	0.895
jd (2nd method)	0.0697	0.0516	.....	0.1164	0.0422	0.1235	0.1062	.....	0.1024

Run	78	82	88	92	160	122	161	129	131
Particle description	Large lead shot			Small lead shot		Rape seed		Glass beads	
State of bed	Fixed	Fluid	Fluid	Fluid	Fluid	Fluid	Fluid	Fluid	Fluid
Part. diam., in.	0.0792	0.0819	0.0735	0.0302	0.0275	0.0786	0.0758	0.0286	0.029
Vel., lb./hr. air	25.0	322	135	282	69.0	233.5	212	211.5	20.3
PP gas out, mm. Hg	0.0765	0.0441	0.0575	0.0558	0.0458	0.0194	0.0268	0.02185	0.0631
Surf. temp., °C.	25.63	23.85	22.30	24.80	19.56	22.07	21.11	18.00	24.81
Col. wt. loss, g.	0.996	1.838	1.024	1.970	0.961	0.725	0.706	0.470	0.408
Surf. area, sq. ft.	1.454	2.08	1.968	2.33	1.82	1.069	1.600	1.580	0.810
Time, min.	12.0	3.00	3.39	3.0	6.96	4.03	3.124	2.500	7.32
k_g, lb. mole /(hr.)(sq.ft.)(atm.)	1.06	4.43	4.02	4.28	2.88	2.35	2.45	2.99	1.18
jd (1st method)	0.1790	0.0584	0.1395	0.0665	0.1750	0.0458	0.0532	0.0637	0.245
Bed ht., in.	0.3	1.15	.45–.51	0.7–1.0	0.3	1.5–2.0	2.0–3.0	1.5–2.0	0.1
Total wt. loss, g.	1.181	.....	.....	.....	1.154	2.616	1.664	1.005	0.537
jd (2nd method)	0.1823	.....	.....	.....	0.1606	0.0480	0.0544	0.0628	0.269

The general shape of the curves is similar to those reported by McCune and Wilhelm (*17*), given in Figure 1, in that the rate of decrease of the mass-transfer factor j_d is accelerated as the Reynolds number moves into the fluidized region. No effect of particle size in the fixed bed was found. This is also the conclusion of most previous investigators (*4, 5, 7, 17, 25*). It is to be noted that there is a definite break or discontinuity in the curves between fixed and fluid beds. Gamson (*6*) has shown that a continuity existed between fixed and fluid beds by plotting $j_d/(1-\epsilon)^{0.2}$ vs. a modified Reynolds number defined as

$$N_{Re}' = D_p G/\mu(1-\epsilon) \qquad (14)$$

The modified Reynolds number was first used by Carman (*2*) and later extended by Morse (*16*) for the purpose of correlating pressure-drop data in fixed and fluid beds.

The mass-transfer factor was correlated with the Reynolds number, and the correlation is graphically presented in Figure 4 for the authors' data in both fixed and fluidized beds. The same data were also treated, as suggested by Gamson (*6*), by including voidage fraction in the ordinate as well as abscissa, as presented in Figure 5. Little improvement in the correlation was noticed even at higher Reynolds number. Moreover, the inclusion of the same variable, voidage fraction, in both ordinate and abscissa may make any testing of correlation insensitive. In general, the graphical representation of data should not involve the same variable in both ordinate and abscissa.

In the present treatment as well as

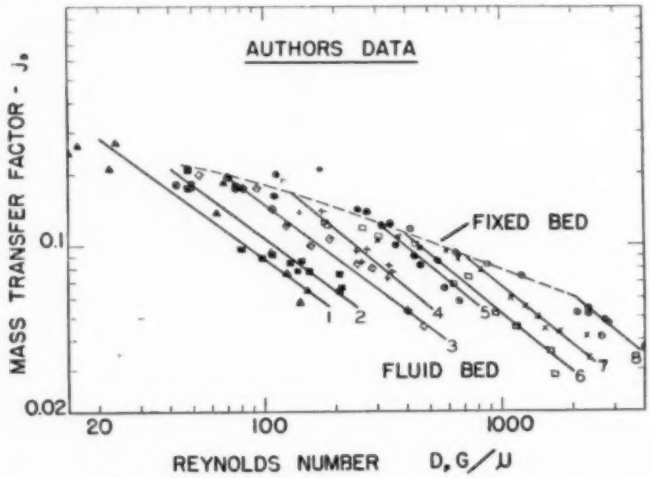


Fig. 3. Representation of authors' mass-transfer data vs. Reynolds number for all coated particles.

		D_p(average) in.			D_p(average) in.
1. Glass beads	△	0.028	5. Large lead shot	⊗	0.078
2. Small lead shot	⊠	0.029	6. Small Celite cylinders	□	0.215
3. Rape seed	◇	0.077	7. Intermediate Celite cylinders	×	0.334
4. Intermediate lead shot	+	0.050	8. Large Celite cylinders	⊙	0.540

that of Gamson (*6*), the discontinuity between fixed and fluid beds disappears, as does the difference of particle diameter in fluidized bed. The data show no effect of particle density, notwithstanding the fact that the initial fluidization velocity is proportional to the particle density. The bed height does not seem to have any effect either on the mass-transfer factor, as was also found by other investigators (*13, 17, 18*). Effects of particle diameter, velocity, and voidage are correlated by the modified Reynolds number for all particle sizes, velocities, and bed voidages investigated.

The authors' data and the data of other investigators, with the exception of Hurt, Kettenring *et al.*, and Resnick and White, are shown in Figure 6. It is to be noted that the data include both fixed and fluid beds using both liquids and gas as the transfer mediums. Consequently, the Schmidt-number group appearing in the ordinate as part of the definition of the mass-transfer factor j_d varied widely from system to system, the range being from 0.6 to 10,600. It is remarkable that data from such diverse

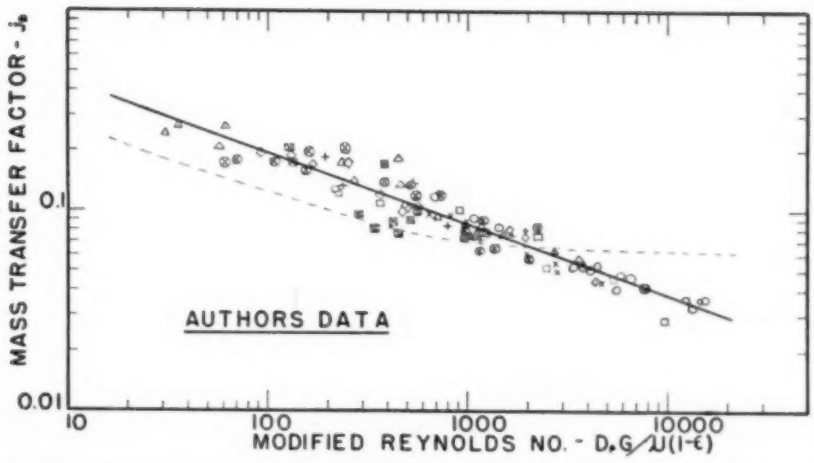


Fig. 4. Authors' data for mass-transfer factors vs. modified Reynolds number for fixed and fluidized beds.

⊙ Large Celite cylinders
× Intermediate Celite cylinders
⊡ Small Celite cylinders
⊗ Large lead shot
+ Intermediate lead shot
⊠ Small lead shot
◇ Rape seed
△ Glass beads

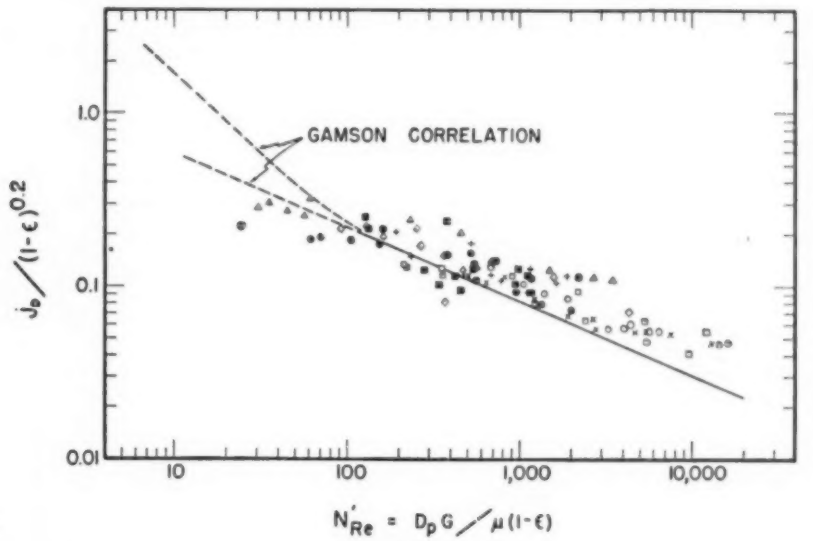


Fig. 5. Mass-transfer factors in fixed and fluid beds. Gamson correlation (authors' data).

⊙ Large Celite cylinders
× Intermediate Celite cylinders
⊡ Small Celite cylinders
⊗ Large lead shot
+ Intermediate lead shot
⊠ Small lead shot
◇ Rape seed
△ Glass beads

systems correlate on a single plot. At the higher Reynolds number, McCune's data, however, for liquid-solid fluidization seems to veer away from the other data reported. The curve seems to have definite regions, the lower modified Reynolds number corresponding to the streamline region, and the higher Reynolds number to the turbulent region, with an intermediate zone in the moderate Reynolds-number range. More data are needed at the extremities to establish definitely the shape of the curve at these points. The equations for mass transfer can be given by

$$j_d = 1.77(N_{Re}')^{-0.44} \qquad 30 < N_{Re}' < 5000 \qquad (15)$$

$$j_d = 5.7(N_{Re}')^{-0.78} \qquad 1 < N_{Re}' < 30 \qquad (16)$$

The data for mass transfer of water vapor from porous commercial-tower packing, as reported by Taecker and Hougen (*22*), are shown in Figure 7, along with data of McCune and Wilhelm for mass transfer of 2-naphthol from flakes into water. The data were replotted using an area factor to multiply the surface area reported. This method of correlating commercial tower packing by using an area factor was first proposed by Gamson (*6*). It is necessary because in the case of hollow commercial tower packings and flakes, not all the area is equally effective in transfer of mass. In other words, the film thickness will vary over the packings in a different fashion from over regular-shaped packings. It is interesting to note that the same area factor sufficed for all the commercial packings tried. Therefore, on the basis of the available data, the over-all correlation might be used to predict the effect of the variables usually encountered in commercial towers, as far as the gas film itself is concerned.

The pressure-drop data for fixed granular beds has been correlated by plotting the friction factors f vs. a modified Reynolds number (*16*). The friction factor for fixed granular beds can be defined as

$$f = \frac{g_c \Delta\pi D_p \rho_f \epsilon^3}{2G^2 L(1-\epsilon)} \qquad (17)$$

A plot of friction factor vs. Reynolds number for fixed granular beds is often called a Carman-Kozeny plot, which represents an average of extensive pressure-drop data for a variety of shapes. Morse (*16*) proposed that Equation (*17*) be also applied to the fluidized bed. The data for the fluidized friction factor, however, scattered around the Carman-Kozeny friction-factor curve for the fixed granular beds. Morse attributed the deviations to slugging and channeling of the particles. The fluidized-friction-factor data taken on the coated particles of this investigation likewise scattered around the Carman-Kozeny fixed-bed curve. Therefore the fixed-bed curve of friction factors vs. modified Reynolds number was used to represent the fluidized-bed data only as an approximation.

Analogy Between Mass and Momentum Transfer

There has been a great deal of interest in the interrelationship of mass, heat, and momentum transfer. The chemical engineer is interested in these relationships for a very practical reason. Pressure-drop data are easily secured, while heat- or mass-transfer data are not. Osborne Reynolds was among the first to suggest a quantitative relationship between these energy transfers. Reynolds's analogy can be simply stated for mass and momentum transfer as (*3*)

$$\frac{f/2}{k_g p_{bm}/G_m} = 1 \qquad (18)$$

This proved to be an oversimplification of the case, for the ratio expressed in the preceding equation varied widely from system to system. The correlating group, of which this ratio seemed to be a function, was the Schmidt number.

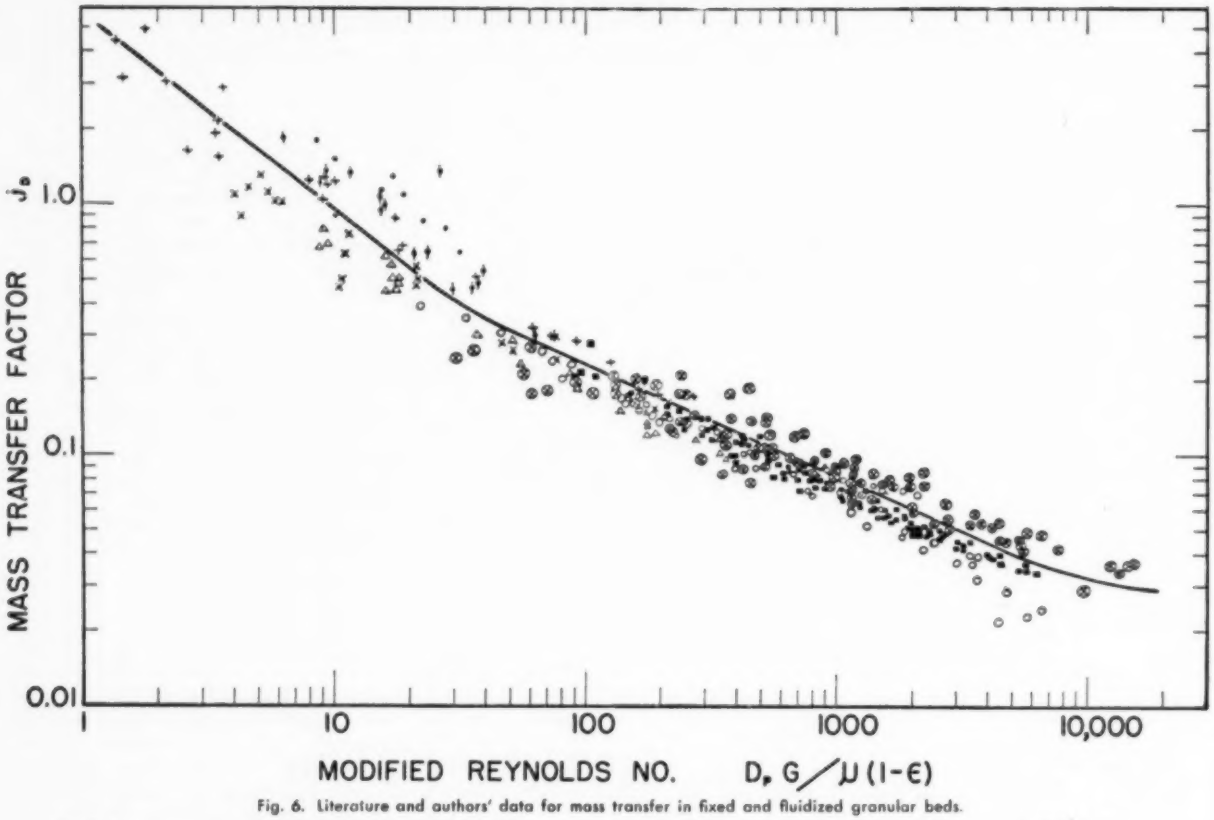


Fig. 6. Literature and authors' data for mass transfer in fixed and fluidized granular beds.

Symbol	System	Schmidt No.	Type of particle	State of bed	Reference
⊗	Naphthalene-air	2.57	Spheres, cylinders	Fixed, fluidized	Authors
■	Water-air	0.60	Spheres, cylinders	Fixed	(5, 25)
○	2-naphthol-water	1400	Modified spheres	Fixed, fluidized	(17)
●	Isobutyl alcohol–water	866	Spheres	Fixed	(7)
◆	Methyl ethyl ketone–water	776	Spheres	Fixed	(7)
+	Salicylic acid–benzene	368	Modified spheres	Fixed	(4)
×	Succinic acid–*n*-butyl alcohol	690	Modified spheres	Fixed	(4)
△	Succinic acid–acetone	164	Modified spheres	Fixed	(4)

Many functions have been proposed from theoretical considerations and Nikuradski's data (*1*) for velocity traverses. Although the interpretation of Nikuradski's original data was questioned by Miller (*15*), the equations based on the data have been moderately successful in predicting experimental data. One of the most successful of these equations, due to Von Karman (*20*), can be stated as:

$$\frac{f/2}{k_g p_{bm}/G_m} = 1/1.6 + (5/1.6)(f/2)^{1/2} \left(1.6N_{Sc} - 1 + \ln \frac{(1+8N_{Sc})}{6} \right) \quad (19)$$

A simplification of functions in the preceding equation was proposed by Chilton and Colburn (*3*):

$$\frac{f/2}{k_g p_{bm}/G_m} = (N_{Sc})^{2/3} \quad (20)$$

The mass-transfer factors for naphthalene, as calculated by Von Karman's analogy, are shown plotted against the modified Reynolds number in Figure 5. The friction factors were taken from

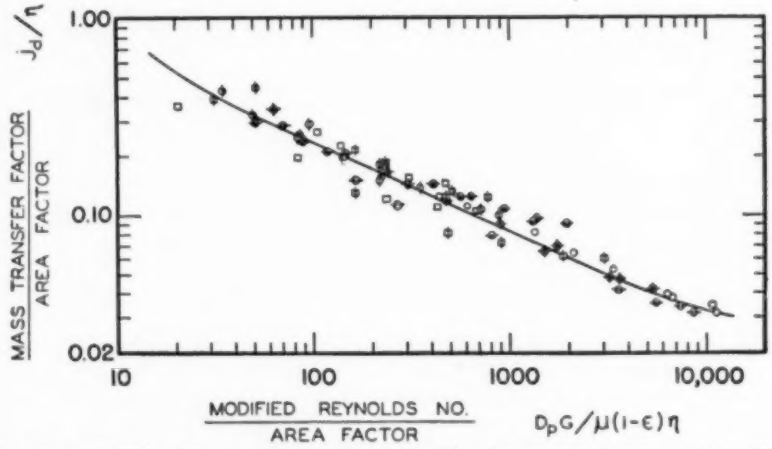


Fig. 7. Mass-transfer factors vs. modified Reynolds number for commercial tower packings (22) and flakes (17) with area factor included.

Particle	Area factor	System
⊞ 8-10 mesh flakes	0.80	2-naphthol–water, fixed and fluid
□ 14-18 mesh flakes	0.80	2-naphthol–water, fixed and fluid
⊖ ½-in. Raschig rings	0.65	water-air, fixed bed
⊕ 1-in. Raschig rings	0.65	water-air, fixed bed
○ 2-in. Raschig rings	0.65	water-air, fixed bed
◑ ¼-in. Berl saddles	0.65	water-air, fixed bed
◐ ½-in. Berl saddles	0.65	water-air, fixed bed
⊖ 2-in. partition rings	0.65	water-air, fixed bed

Line through the data represents all the mass-transfer data in fixed and fluidized beds.

the Carman-Kozeny friction-factor plot. The agreement is fair, the largest deviations being at the higher modified Reynolds number. However, for the other systems, the deviations became quite large. This is shown in Figure 8, where $k_g p_{bm}/G_m$ is plotted vs. the Schmidt number, along with some experimental points, at a constant Reynolds number. On the basis of the data examined, it is proposed that the Chilton-Colburn analogy for flow in conduits be modified for the case of flow in granular beds to

$$\frac{f/2}{k_g p_{bm}/G_m} = 5(N_{Sc})^{\frac{2}{3}} \qquad (21)$$

This equation was also plotted in Figure 8 using the friction factors of the Carman-Kozeny curve. From the definition of the mass-transfer factor and rearrangement of Equation (21), one may write:

$$j_d = f/10 \qquad (22)$$

A plot of the mass-transfer factor, j_d, and 1/10 of the friction factor, $f/10$, vs. the modified Reynolds number, is shown in Figure 9. The agreement is good considering the wide range of Reynolds number covered.

Correlation of Voidages in a Fluidized Bed

In order to be able to use any of the correlations presented thus far, it is necessary to know the voidage. For the fixed bed this is usually known, or easily obtained. For the fluid bed a correlation was developed for the prediction of the bed voidage in the turbulent region where all the data of this investigation were taken in the range of modified Reynolds number greater than 30. The correlation is based upon an extension of the Carman-Kozeny turbulent-region equation for pressure drop in fixed granular beds to the fluidized region. The equation representing this curve is given by (*2, 12, 24*):

$$V = \frac{S^{1.9}\rho_f \epsilon^{3/1.1} D_p^{1.1} \Delta\pi g_c^{1/1.9}}{2.9(1-\epsilon)^{1.1}\mu L} N_{Re}' > 30 \qquad (23)$$

Since the pressure drop at fluidization is constant, equal approximately to the weight per unit area, one can write the pressure drop, per unit of bed height, in terms of the voidage, and the density of the particle as

$$\Delta\pi/L = (1-\epsilon)\rho_p \qquad (24)$$

Substituting Equation (24) in (23) and considering gas density, viscosity, and shape factor as part of the constant c, one may write for the turbulent region:

$$V = cD_p^{0.578}\rho_p^{0.526}\frac{\epsilon^{1.578}}{(1-\epsilon)^{0.0526}} \qquad (25)$$

Therefore, for any given particle, a plot of the voidage function, $\epsilon^{1.578}/(1-\epsilon)^{0.0526}$, vs. velocity, should result in a straight line going through the origin. Typical voidage data are shown in Figure 10. In each case a line was drawn through the origin and the data. Data of other investigations (*11, 24*) in the turbulent region give similar straight lines when plotted on this basis. The slopes of the straight lines through the origin of Figure 10 and of similar lines of the other investigators (*11, 24*) are plotted vs. the product of the bulk density and the particle diameter in Figure 12. The equation for the slope of the voidage function vs. the velocity was thus found graphically as

$$m = 2.59 \times 10^{-4}(\rho_b D_p)^{-0.79} \qquad (26)$$

The bulk density under fixed-bed conditions, rather than the particle density, was used because it was found that the former gave a better correlation. If the voidage expansion had followed Equation (25), the exponent on the product of the bulk density and the particle size would have been in the neighborhood of 0.55. The exponent 0.79 suggests that the expansion is not fully described by the Carman-Kozeny fixed-bed equation. A nomogram based on Equation (25) to give the voidage was constructed (*12*) to save time in calculation. The initial fluidization velocity may be calculated from Equation (25).

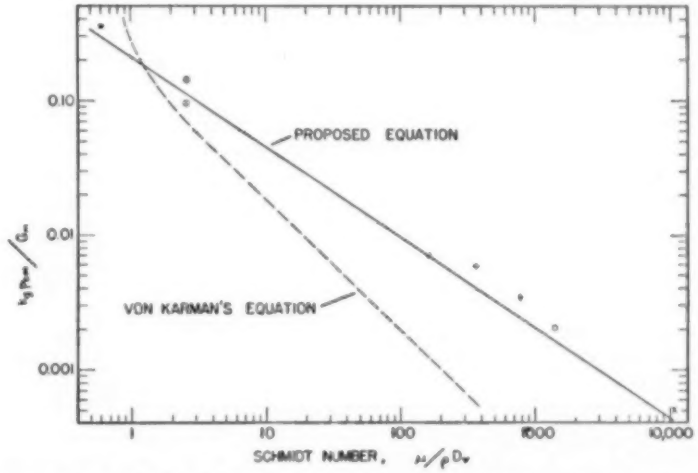


Fig. 8. Comparison of data with Von Karman's and proposed empirical equation for the analogy between mass and momentum transfer (based on a modified Reynolds number of 70, and Carman-Kozeny friction factors).

Symbol	System	Reference
⊗	Naphthalene-air	Authors'
■	Water-air	(5, 25)
△	Succinic acid–acetone	(4)
+	Salicylic acid–benzene	(4)
•	Methyl ethyl ketone–water	(7)
○	2-naphthol–water	(17)
×	Succinic acid–n-butyl alcohol	(4)

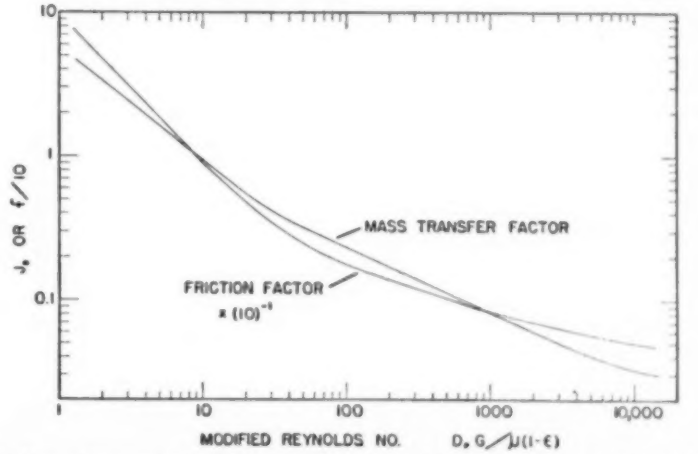


Fig. 9. Mass and momentum transfer in fixed and fluidized beds. Comparison of jd and f/10 vs. modified Reynolds number (friction factor curve shown is that of Carman-Kozeny divided by 10).

using the initial voidage, or it may be determined experimentally. When the nomogram is used to predict the observed voidages, a root-mean-square deviation of 11% was obtained based on the observed values. A maximum deviation of 42% on the small lead shot was observed.

Discussion of Errors

It is desirable to know quantitatively what the error is in the final calculated quantities when the errors present in each of the experimental quantities are known. If y is a function of x_i, then the equation for the propagation of error is given as (*21*)

$$(dy)^2 = \sum_{i=1}^{n} (\partial y/\partial x_i)^2 dx_i^2 \qquad (27)$$

Applying Equation (*27*) to the definition of k_g, and cancelling out the appropriate terms when Equation (3) is used to calculate the outlet vapor pressure, the result is (*12*)

$$(dk_g/k_g)^2 = (Bd\theta/\theta)^2 + (Bdp_s/p_s)^2 + (Bd\Delta W/\Delta W)^2 + (B-1)(dG/G)^2 + (dA/A)^2 \qquad (28)$$

where

$$B = \frac{x/(1-x)}{\ln(1/1-x)} \text{ and } x = p_g/p_s.$$

B is a function of the fractional approach of the exit gas to saturation, and when B is plotted vs. the fractional approach to saturation, p_g/p_s, it may be seen (*12*) that the experimental errors are magnified by a factor of 4 at 90% saturation when used to compute the mass-transfer coefficient, k_g. After 90% saturation the degree of multiplication of experimental errors increases sharply, making precise measurements in this region quite difficult. For this reason no measurements were made above 90% saturation. It is interesting to note that the error function for the mass-transfer factor using the first method of calculation described earlier in the paper came out to be (*12*)

$$(dj_d/j_d)^2 = (Bd\theta/\theta)^2 + (Bdp_s/p_s)^2 + (Bd\Delta W/\Delta W)^2 + (BdG/G)^2 + (dA/A)^2 \qquad (29)$$

The error involved in the second method of calculation of the mass-transfer factor is given by (*12*)

$$(dj_d/j_d)^2 = (Cd\Delta W/\Delta W)^2 + (dA/A)^2 \qquad (30)$$

where

$$C^2 = B^2(1 - 2x + 2x^2) \qquad (31)$$

When C is plotted vs. a function of the fractional approach to saturation, p_g/p_s, the shape of the curve (*12*) is seen to be very similar to that of the multiplication factor B of the preceding equations. Comparison of Equation (30) with (29) illustrates that the number of experimental errors that are magnified are greatly reduced. Therefore, Equation (9) represents a more accurate means of calculation. Both methods of calculation were used in the calculation of the mass-transfer factor, as illustrated in Table 2. However, the first method of calculation was used in plotting the curves, because in some runs in order to get maximum gas velocity the saturator was not used.

It is desirable to know what the error in the estimation of the mass-transfer factor might be, knowing the possible error in the voidage, and assuming that this is obtained from the nomogram. From Equations (15) and (*27*), assuming that only the errors made in the computation of the voidage were significant as compared to the other errors, the error in estimating the mass-transfer factor can be written as:

$$(dj_d/j_d)^2 = 0.44(\epsilon/1-\epsilon)(d\epsilon/\epsilon)^2 \qquad (32)$$

when $0.44(\epsilon/1-\epsilon)$ is plotted vs. the voidage. It is seen that below a voidage of 0.7, the error is actually reduced, while above a voidage of 0.7 the error is magnified. These facts should be kept in mind in using the nomogram (*12*) in conjunction with the over-all correlation.

A quantitative estimate of over-all error in the measurement of j_d can be given by determining the maximum error to be expected. From Equations (*4a*) and (*27*) the following expressions for the maximum error can be derived, since maximum vapor pressure error was about 5%:

$$(d\theta/\theta)^2 + (dp_s/p_s)^2 + (d\Delta W_c/\Delta W_c)^2 + (d\Delta W_s/\Delta W_s)^2 + (dG/G)^2 = (0.05)^2 \qquad (32)$$

By assuming that the error in the saturator weighings, $(d\Delta W_s/\Delta W_s)$, is negligible, one can substitute the foregoing equation into Equation (*29*). If one does not make this assumption, the error in the substitution will be less than 0.05. The maximum multiplication factor B in Equation (*29*) would be 4.0, corresponding to a fractional approach to saturation of 90%. The error in measuring the surface area was estimated to be about 10%. Therefore the maximum error from Equation (29) is given as

$$(dj_d/j_d) = \sqrt{4^2(0.05)^2 + (0.10)^2} = 22.3\%$$

Summary of Results and Conclusions

1. Mass-transfer data for aggregative-type (gas-solid) fluidization are in agreement with other mass-transfer data in the fixed beds as well as with the data for particulate (liquid-solid) -type fluidization. All the mass-transfer data for both types of fluidization, as well as for stationary beds, for widely varying systems can be correlated on a plot of mass-transfer factor j_d vs. a modified Reynolds number $D_pG/\mu(1-\epsilon)$.

2. The variation of bed voltage ϵ can be incorporated into the modified Reynolds number. During the course of the investigation, the bed voidage was var-

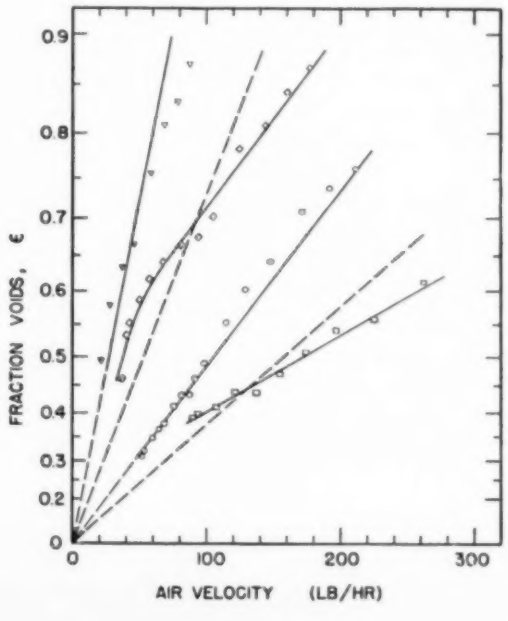


Fig. 10. Fluidized bed voidage vs. air velocity. Voidage scale determined from the function.

▽ Glass beads
◇ Small lead shot
○ Small Celite cylinders
□ Intermediate lead shot

ied from approximately 0.25 to 0.97.

3. Mass-transfer and pressure-drop data for granular beds are related by the simple equation $j_d = f/10$.

4. Mass-transfer factors, like friction factors, are independent of bed height. For the runs made, the quiescent bed height was varied from 0.1 to 3.6 in.

5. Mass-transfer factors in a fluidized bed are independent of particle density, except that the particle density is an important factor in determining the initial fluidization velocity. The particles used varied in density from about 1 to 9 g./cu.cm.

6. The effect of particle size can be correlated by the use of the modified Reynolds number. The particle size was varied from about 0.03 to 0.5 in.

7. The mass-transfer data in granular beds can be correlated by:

Equation	Range of Modified Reynolds Number
(*a*) $j_d = 1.77(N_{Re}')^{-0.44}$	30 to 10,000
(*b*) $j_d = 5.7\ (N_{Re}')^{-0.78}$	1 to 30

8. The voidage in the fluidized bed in the turbulent region can be predicted for use in the preceding equation by means of a nomogram (*12*) developed from the extension of the Carman-Kozeny equation to the fluidized bed.

Notation

A = total particle surface area in column, sq.ft.
a_w = particle surface area per unit weight, sq.ft./lb.
$B = x/(1-x)/\ln(1/1-x)$
D_c = diameter of cylinder, ft.
D_p = diameter of particle, ft.
D_v = diffusivity of vapor in gas, sq. ft./hr.
f = friction factor $= \dfrac{g_c \Delta\pi D_p \rho_f \epsilon^3}{2G^2 L(1-\epsilon)}$
G = mass velocity, superficial, lb./(hr.)(sq.ft.)
G_m = mass velocity, superficial molar, lb. mole/(hr.)(sq.ft.)
g_c = gravitational constant, ft./(hr.)(hr.)
j_d = mass-transfer factor
k_g = mass-transfer coefficient, lb. mole/(hr.)(sq.ft.)(atm.)
L = bed height, height of cylinder, ft.
M = molecular weight, lb./lb. mole
m = slope of line, (hr.)(sq.ft.)/lb.
M_r = molecular weight ratio, air to naphthalene
N = number of particles
N_{Re} = Reynolds number, $D_p G/\mu$
N_{Re}' = modified Reynolds number
N_{Sc} = Schmidt number, $\mu/\rho D_v$
p_g = partial pressure of naphthalene in gas stream, atm.
p_s = vapor pressure of naphthalene at solids temperature, atm.
p_{bm} = mean partial pressure of air in gas film, atm.
Δp_{lm} = log mean partial pressure driving force of naphthalene in gas stream, atm.
S = column cross-sectional area, sq.ft.
T = absolute temperature, ° K.
t = temperature, ° C.
V = velocity of air, lb./hr.
W = weight, lb.
ΔW_c = weight loss of column charge, lb.
ΔW_s = weight loss of saturator charge, lb.
x = ratio of exit-gas partial pressure to vapor pressure of solid $= p_g/p_s$

Greek Letters

η = area factor
θ = time, hr.
π = total pressure, atm.
$\Delta\pi$ = total pressure drop across bed, atm.
μ = viscosity, lb./(hr.)(ft.)
ϕ = shape factor
ϵ = bed voidage
ρ = density, lb./cu.ft.

Subscripts

b = inert (air), bulk
c = cylinder
f = fluid, fluidized
g = gas
lm = log mean
M, m = molar, mean conditions
p = particle
s = solid surface, saturator
w = weight basis
1 = inlet conditions

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Discussion

R. H. McBride (Du Pont Company, Niagara, N. Y.): Did you find any abrasion of the fluidized particles that would carry out of the reactor as fines and thus influence your weight determinations and loss?

James Kalil: At the top of the column we had two cloth filters and, sandwiched between these, several layers of glass wool which formed part of the column and therefore part of the weight. After each run these filters were held up to the light to see if any naphthalene particles were present. If there were any particles, or even a suspicion of particles, we threw out the run. With relatively high bed heights, using large particles, we did get some attrition and therefore could not take any data at these bed heights. Thus attrition was a factor limiting the bed height for large-sized particles.

R. H. McBride: Did you have any difficulty in observing the bed height? In other words, was there much variation in average bed height or was it fairly uniform?

James Kalil: There were variations in the fluidized bed heights. We would observe first an average maximum bed height and then an average minimum bed height. These would then be averaged to give the bed height used in the calculations. This does represent an approximation and therefore accounts for a good deal of the scatter in the plots of the experimental data.

(Presented at A.I.Ch.E. Rochester (N.Y.) Meeting.)

Much of the future of chemical engineering is tied up in the science of rate processes in chemical reactors. Here is the address of the 1952 winner of the Professional Progress Award in Chemical Engineering, R. H. Wilhelm, professor of chemical engineering at Princeton University. He is one of the country's outstanding authorities on the subject, and this review is intended not only for those new to the subject, but also for those experts to whom a lucid and clear picture of the art is always appealing.

Rate Processes in Chemical Reactors

Richard H. Wilhelm

Princeton University, Princeton, New Jersey

The chemical reactor is a meeting ground for many representative types of rate processes that are encountered throughout a chemical plant. The speed of chemical reaction and heat release in these devices must be balanced by diffusional rates for matter and for heat, and by the flow of material under a variety of circumstances. The balance between chemical rate processes and the physical processes of flow and diffusion serves to provide an environment in which the production of desired chemical products may occur with economic conversions, yield and purity. It is this interplay of physical with chemical variables that distinguishes to a large extent small-scale chemical experiments in the laboratory and the operation of large-scale industrial reactors. Use of small dimensions in laboratory equipment frequently permits diffusional effects to be minimized so that the characteristics of the chemical system may be studied as the prime process. Because of the large dimensions of industrial reactors, coupled with high production rates and high heat- and mass-transfer rates, differences in temperature and concentration from point to point within such reactors may be expected to develop. One commonly must accept such differences. As a process is developed through various changes in scale between laboratory and plant, it is the problem of the designer to see to it that gradients and limits in conditions in the final unit are held within allowable values insofar as the requirements of the chemistry of the reaction are concerned. Examples of such requirements are a minimum formation of by-product, an assurance of catalyst activity over a long period, and safety in plant operation.

Chemical reactors have been built for considerably more than fifty years. The chemical industry has been successful in making new products for the nation's needs. Newer forms of reactors have come into being in the recent past. Reactions in jets and among suspended particles in fluidized beds are taking their place as reaction arrangements alongside the agitated vessel, the tank reactor and the flow tube. An increase is noted also in intensity of reaction conditions—higher temperatures, higher pressures, shorter times of contact. An ever-expanding array of types of chemical reactions is being used in the commercial production of chemicals. In most instances the development of chemical reactors has occurred in a systematic program of experimental translation from one scale to the next, wherein one learns about and masters new variables as these appear. The imaginative chemist and chemical engineer, in proceeding toward the objective of a new process, have not waited for the explicit solution of differential equations. He has generally chosen, in effect, to solve the equations inherent in the system by performing experiments in a development program with a reasonable assurance in this procedure that major assumptions have not been overlooked. There can be no objection to this direct, effective, experimental procedure except that it is costly and time consuming.

In the last twenty years or so a rise of interest has been noted in the engineering and scientific foundations upon which the operation of chemical reactors and other processing equipment in the chemical plant depend. At present, for example, attention is being directed at fundamental problems in a scientific sense, such as the nature of turbulence, or the relation of the electronic structure of metals and oxides to catalysis, or the nature of the competition between the rearrangement of energy within a molecule and between molecules in chemical reaction, when both rearrangements take place with the same order of velocity, as in combustion. On another level, in studies basic to the engineering aspects of reactors, there has been a steady growth of interest by workers in a sub-

Among the A.I.Ch.E. award winners of 1952 is Richard H. Wilhelm, professor of chemical engineering, Princeton (N.J.) University, who became the fifth recipient of the Professional Progress Award sponsored by the Celanese Corporation of America and administered by the American Institute of Chemical Engineers. This time recognition was given for "his distinguished contributions to the theories and experimental data of fluid mechanics. . . ." This same professor only the year before had been honored by the Institute when he became the sixteenth recipient of the Institute's William H. Walker Award. Born in New York City, Professor Wilhelm received his B.S. and Ch.E. degrees from the Columbia School of Engineering and a Ph.D. from the Columbia Graduate School.

stantial number of university and industrial laboratories. Effective studies have been directed toward a satisfactory formulation, for engineering purposes, of chemical rate equation for complex systems—particularly for the important class of solid-catalyzed gaseous reactions. The differential reactor as a proper arrangement for taking experimental rate information in flow systems has received wide acceptance. Other studies have been directed toward the flow of fluids and the transfer of heat and mass under different physical circumstances: across phase boundaries, and within single phases in tubes, through packings, within porous solids, for example. Some investigators have brought mathematical tools to bear on solutions of the conservation equations when chemical reactions are performed in model situations. A sampling of problems might include the effect of the velocity profile in a tubular reactor on chemical reaction and conversion, or the effect of diffusion within the pores of a catalyst pellet on the productivity of a reactor, or the mathematics involved in dissolving a gas in a liquid with which it subsequently reacts. It is unfortunate that the investigator runs quickly into insurmountable mathematical complexity in attempting general solutions for all but the simplest situations or special cases. Increasingly, the chemical engineer is being confronted with the necessity of employing numerical rather than general, analytical methods in the solution of problems that pertain to his profession.

One may well ask of what value is a background of basic engineering knowledge if it cannot, except in limited instances, be put to full direct use in a mathematical sense in the complex compromises of design? The point is that such background *is* employed as an ingredient of engineering judgment. It is involved in the very questions that are asked for which an experimental reactor program is expected to provide answers. Does the effect of catalyst pore size in cracking reactions result from basic chemical processes in narrow spaces, or from the presence of pore diffusional effects? In a high-capacity catalytic reaction, will a change in temperature lead to a gain in conversion or do diffusional effects control the operation with a consequent small effect of change in temperature? Is a chlorination of liquid benzene controlled by the rate of heat removal, by the rate of gas absorption, or by chemical steps and how can such a process be improved? In setting up a program of developmental experiments not only is primary chemical knowledge needed, but also is background required regarding elementary diffusional rate situations and how these are affected by temperature, pressure, concentration, and flow rate.

A number of reactor problems fortunately do lend themselves to computational analysis and here engineering judgment enters into the selection of the various chemical and physical mechanisms that shall be represented in the analysis. In this connection present industrial activity in supplementing experimental reactor programs by parallel computational programs using modern machine methods may be significant.

The purpose in writing a paper of this kind may best be served perhaps by limiting the subject somewhat at this point and focussing attention upon a single area of interest. Accordingly, this paper will cover, in a general way, certain diffusional mixing processes that occur as a gas or liquid flows through masses of particles in fixed- or fluidized-bed reactors. The physical picture of what may be happening will be stressed and implications of the mixing behavior on chemical reactions will be indicated.

To start with, mixing in its present meaning refers to random fluctuations of matter that tend to diminish temperature and concentration gradients. Well-known examples are molecular and turbulent diffusion of liquids and gases. The flow of a fluid around particles in a packed bed causes a random sidestepping action which also is a coarse type of mixing.

Figure 1 considers several types of diffusional processes that are apparent in a packed bed and processes in which they are encountered.

As shown in Figure 1 (a) it is possible to have diffusion of mass or heat across boundaries between the particles and the fluid stream. This transfer step is a central one in many of the phase-change separations that concern the chemical engineer, such as gas absorption, extraction or drying. Also, an interfacial diffusion resistance around a catalyst pellet in a chemical reactor serves to establish a temperature difference between the stream and pellet during reaction. Major emphasis has been placed on this type of process and many studies concerning it have appeared in the literature. Today it is desirable to emphasize processes that occur within a fluid phase rather than across phase boundaries. Mechanisms b, c, d, and e are illustrative of intraphase diffusion.

Step (b) is concerned with the diffusional behavior of heat or material in the space between the particles of a bed. This is also true of (c), but (b) is in a radial direction. This interparticle mode of radial heat transfer is of importance, for example, in fixed-bed catalytic reactors. As is well known, a temperature maximum, or hot spot is formed in the center of the tube for an exothermic reaction even when one attempts to make

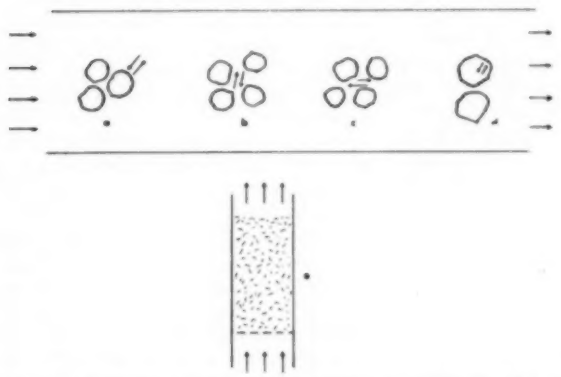

Fig. 1. Representative types of diffusional steps among particle and fluid streams.

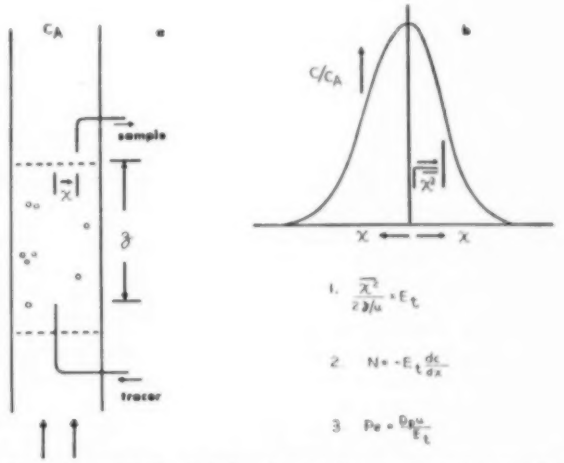

Fig. 2. Tracer-injection technique for diffusion measurement, apparatus and type result.

the reaction as isothermal as possible by keeping the tube wall temperature constant throughout its length. If we exclude radiation from consideration, the main way that heat is dissipated radially from the hot spot to the wall, and the way in which reactants also are transported radially, is by the mixing processes that occur in the spaces between the catalyst particles. To analyze in any quantitative sense the temperature distribution within a catalyst bed, including the hot spot, or minimum in the case of endothermic reaction, information is necessary regarding the coefficient of transfer for mechanism (b).

Interparticle diffusion also is an important rate process in the maintenance of temperature and concentration uniformity in fluidized beds. The arrangement of (b) for fixed beds, and (d) for fluidized beds, are linked in this paper because the same experimental technique may be used to measure radial gradients in both instances. Most readers of this paper are aware of a fluidized bed as a dense mass of particles that is suspended as a result of the upward motion of a fluid between the particles. The contact between this mobile mass of particles and the suspending fluid may be utilized in catalytic reactions, in adsorption or in other mass- or heat-transfer operations. A fluidized bed evolves quite logically by the "melting" of a fixed bed; it is interesting to observe the transition in diffusional properties from one of these states to the other.

Mechanism (c) is similar to (b) except for the direction of action. In (c) there is diffusion in the continuous phase between particles in the axial direction. This mode of heat or mass transfer does not become important in chemical reactors until high axial gradients are achieved in extremely rapid reactions in packed beds. It is a variable that can affect the shape of adsorption waves in high velocity adsorbers. Axial diffusion is relatively difficult to measure directly because of the necessity of imposing concentration or temperature gradients in the axial direction in which the main body of fluid is flowing.

The final diffusional process here considered within a phase is (d), the diffusion of a gas within the pores of a pelleted material such as might, for example, be a catalyst carrier of porous alumina, silica gel, or diatomaceous earth. The rate at which reactants and products can diffuse into and out of pellets has a bearing on how large the pellets should be for a given chemical reaction. The balance between chemical and diffusional rates determines the effectiveness with which the active catalytic material is used throughout the pellet. One may look also at diffusion within particles from the viewpoint of the chemical reaction taking place. If, for example, it is desired to learn something about the chemical nature of the reaction taking place on surfaces deep within the pellet, it is prudent to correct raw experimental rate data for intraparticle diffusion. Erroneous conclusions otherwise can be drawn.

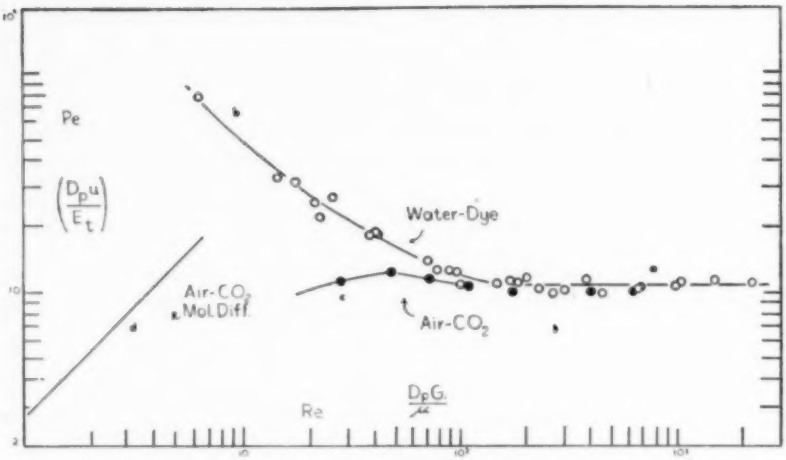

Fig. 3. Radial diffusion in packed beds, N_{Pe} vs. N_{Re}.

With this listing of the types of diffusional rate processes and an indication of where they may be important, one can now turn to a well-known experimental procedure as shown in Figure 2.

In a chemically active bed of particles each particle ordinarily is either a source or sink of heat or material. The material or heat originating at each source flows downstream and spreads radially because of the total of all diffusional rate processes that are operative. An old and well-known fluid mechanics technique (Fig. 2 a) to measure these radial rate processes is by the artificial injection of heat or mass at a point source within the bed. This technique is being used increasingly among chemical engineers. For example, to measure radial diffusion in water as it flows through an empty tube or through a bed of particles, a tracer dye may be injected. In case of gas flow, a second, analyzable gas is the tracer. At any distance, z, down the tube, one obtains a radial profile of concentration vs. the radius, x, as shown in (b). Because true diffusional processes of all types involve randomly fluctuating motions, a normal error curve is obtained when diffusion is limited to the central part of the container. A convenient single number by which a curve of this type, and hence the amount of diffusional spreading, may be characterized is the *root mean square displacement*, $\sqrt{\overline{x^2}}$ sometimes known as the standard deviation. The farther we go along the tube in the z direction, the longer the time elapsed, and the greater the amount of the spread. This idea is incorporated in Equation (1), the Einstein equation for diffusion in which $\overline{x^2}$ is recognized as the mean square displacement, z, the distance between tracer source and the sample point and, u, the point velocity. E_t is the desired diffusion constant resulting from the total of all diffusional processes. It is the diffusion constant also in the alternate and familiar Fick's law, Equation (2), in which N represents moles diffusing per unit area and unit time and dc/dx is the concentration gradient. It is convenient, and also theoretically proper, to express the diffusion constant, E_t, as an ingredient of a dimensionless Peclet group, $D_p U/E_t$, D_p being particle diameter, and U, the point velocity.

In Figure 3 a composite of diffusional data by Latinen (5) is given with the Peclet group as ordinate and Reynolds number based on particle diameter as abscissa. Here is represented information for water and air as the flowing streams for packings ranging from 1.0 mm. to $\frac{3}{8}$-in. diam. and for experiments conducted in 2-in. and 8-in. diam. tubes. These curves for interparticle diffusion are generalized design curves in the sense that friction-factor-Reynolds number plots are for fluid-friction problems. Three major parts to these curves are noted each with different slopes. It may therefore be anticipated that at least three mechanisms for diffusion are represented.

The most important zone of behavior is (a) in which the Peclet group is independent of Reynolds number and has a value of slightly less than 12. There appears to be no significant difference whether a liquid or gas is flowing. The constancy of the Peclet group gives information that in this regime the diffusion constant, E_t, increases linearly with the fluid velocity and with the particle diameter. Such a linear variation with fluid velocity is characteristic of fully developed turbulence. A mechanism has been proposed by several investigators to explain the contribution of particles to the mixing process. As

a small packet of fluid approaches a particle it must, in effect, side-step a certain fraction of the particle diameter to get by it. As the fluid packet then approaches a particle in the next layer downstream, the side-stepping operation again takes place. An essential part of the process is that fluid in the pore space behind a particle, which is fed by rivulets from several directions, must be so thoroughly mixed that a molecule in the pore *on the average*, is as likely to leave by any of the downstream exit paths. These ideas have been formalized in the statistical procedures of the random walk. The formula that results is consistent with experiment on two counts; Pe is predicted to be constant and its value should be of the order of 11, which is close to the experimenal value. Zone (a) therefore appears to be well anchored by agreement between experiment and theory. The theory also reveals that the scale of turbulence within the pores depends only on the particle diameter and that the intensity of turbulence is constant and has a value not far removed from one-half the average fluid velocity. This is a high turbulence intensity. The zone suggests itself for a reactor operation in the performance of rapid reactions under well-controlled and uniformly distributed turbulence conditions, when mixing and reaction must be close-coupled for success provided, of course, that surface effects are not important in the reaction and high pressure drop may be accepted. The zone is one in which plant-scale catalytic reactors normally are found to operate. For such reactors the experimental value of the Peclet group may be used to estimate the catalyst temperature rise above tube wall, by the rough approximation of Damköhler (*2*) or by Baron's (*1*) adoption of the Binder-Schmidt graphical analysis.

A critical Reynolds number is evident in Figure 3 at a value of about 100 or 200. Below this critical condition, full turbulence for mixing no longer exists. Friction plots do not show full turbulence at this Reynolds number with respect to pressure drop. However, independent measurements of heat transfer in packed beds also lead to a mixing transition in the same region.

Below the critical N_{Re}, experimental results for water and air are seen to split and go their separate ways, as in curves (b) and (c) in Figure 3. Fortunately, the injection of dye into water permits observation of the action as an experiment progresses along curve (b) to lower Reynolds numbers, and incidentally to poorer mixing, since E_t is decreasing rapidly. Initially at N_{Re} of 100, the mixing of tracer dye at any given point is fine-grained. As the velocity is lowered, discrete viscous filaments of fluid are seen to retain their identity. It is as though one were performing Reynolds famous experiment but in a disturbed field. A mixing action takes place as the streams split, and split again, as they flow around and off individual particles. At best the mixing due to stream-splitting is coarse-grained. Although the average sampling procedure appears to give a smooth, normal-error composition curve, in fact there are high concentration gradients from point to point within the fluid. At the lowest flow rates, a limit is reached when a single filament winds in a tortuous path around successive particles. Whatever diffusion then occurs is the slow and ineffective liquid-phase molecular diffusion.

In the case of gaseous diffusion as in (c) of Figure 3 the Peclet curve does not first rise as is characteristic of filament formation, but it tends to approach directly the curve for molecular diffusion in which E_t simply is the molecular diffusion constant. A filament does not tend to form in the case of the air experiments because the amount of lateral molecular diffusion that can take place in the time the fluid flows the distance of one particle diameter is substantial.

In brief, then, in an intermediate region between $N_{Re} = 1.0$ and 100 one may anticipate different uniformities of mixing depending upon the molecular diffusion of the system, particle diameter and fluid velocity. This region is precisely the one in which the laboratory experimenter with a small-scale catalyst tube normally is likely to operate unless special action is taken to increase the Reynolds number beyond 100. Regarding this region pertinent questions may be asked. How does filamentous mixing affect chemical reactions in packed beds? Does filamentous mixing become important in high pressure gaseous reactions in which molecular diffusivity is small compared to atmospheric operation? Below the critical N_{Re}, flow patterns are sensitive to conditions. May one therefore expect a convective turnover of reactor vessel contents because of temperature gradients such as occurs in low velocity heat transfer in pipes? These topics have received little or no investigation. They are indicative of many unexplored areas of reactor technology.

Another interesting type of reactor involving particulate solids is the fluidized-bed reactor. This reactor is as complex a piece of machinery as the chemical engineer must deal with. A reactant gas when passed upward through a powdered catalyst causes the solids to undertake a variety of mixing actions. It is clear from recent experience with these reactors that the contact between reactant and catalyst is not as complete in all instances as could be desired. Part of the gas apparently passes through the bed in bubbles or gaseous discontinuities. This behavior may be demonstrated even on a laboratory ½-in. reactor which, during the reaction of hydrogen with ethylene over a fluidized catalyst, will indicate that as much as 40 to 70 per cent of the entry gas can escape without adequate contact. Why do the bubbles form? Why do they grow by aggregation as they rise through a bed? What type of forces between particles is involved? Answers to such questions would lead more logically to remedial steps in improving reactor action. Though ready answers are not at hand, it is possible to show how diffusion experiments with point injection of tracer material may help to define the problem.

To start with, it is sometimes a good idea to back away from a complex problem temporarily and to study a highly ideal counterpart. This can be done with a water-fluidized bed of light particles, such as glass beads. Here, as is well known, the particles are separated, and move about individually with random motion. Suggestions of only minor bed nonuniformities are apparent to the eye. A centrally injected dye stream assumes the usual shape of a spreading plume and radial concentration gradients may be measured. Figure 4 shows how the N_{Pe} group for a fluidized bed compares with fixed-bed diffusional behavior (*5*). Data for packed beds, fluidized beds and empty tubes are presented in one plot by defining the length term in the N_{Pe} and N_{Re} groups as an hydraulic radius, m, which is the total free volume divided by the total area of particles plus tube wall.

The fixed-bed curves, previously discussed, may be noted. A fluidized bed is generated from a fixed bed at the fluidizing point. The N_{Pe} group first decreases (and the diffusivity increases) until a fraction void of about 70 per cent is reached. Beyond 70 per cent void, the particle population decreases rapidly and the diffusional behavior is seen to evolve toward that for an empty pipe in turbulent flow, as represented by the data of Towle and Sherwood (*7*).

Although the evolutionary changes between fixed beds, fluid beds and empty tubes are interesting because they show the relative effectiveness of each arrangement, still more interesting is the difference in diffusional action between this ideal bed and one which is less so. In a water-fluidized bed of lead shot, selected for the high-density difference between solid and fluid, the motion of particles in many cases occurs as vortices. Large vortices of solids may form at the bottom of the tube and smaller ones break off, an action similar to that of a true fluid behind a sphere. Under

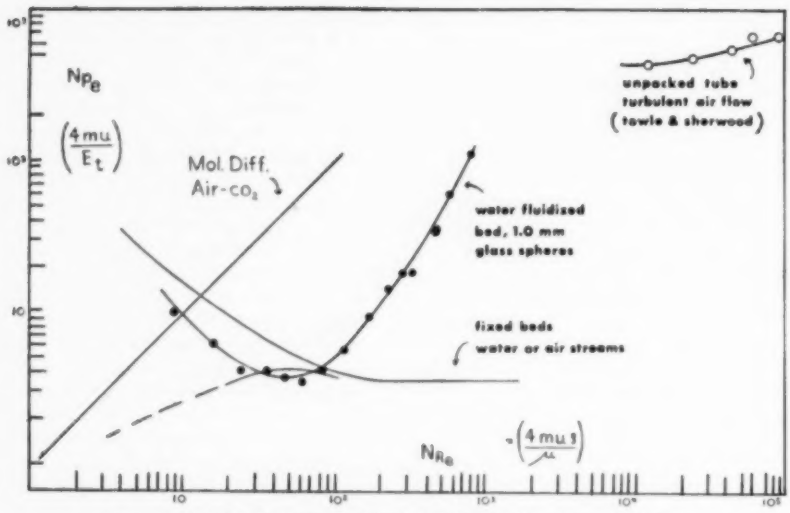

Fig. 4. Radial diffusion in packed beds, fluidized beds and unpacked tubes.

other circumstances, the vortices are more or less uniformly distributed, continuously moving about, breaking down and reforming. Recent data by Hanratty (*4*) indicate notable differences in diffusional behavior in lead and glass bead systems. Visual observations also are suggestive. Vortex action is noted to lead to zones of low particle concentration. The question might be asked if these regions of low particle population, resulting from the angular momentum of the vortex, could be considered as forerunners of bubble formation? In the case of masses having less kinetic energy than particles of lead shot, such as in normal gas-solid fluidization with finely divided particles, are bubbles incomplete and unstable vortices? Rotating masses of particles may attract one another, providing thereby a possible mechanism for the observed phenomenon of bubble coalescence in the fluid-powder technique.

One of the diffusion models listed in Figure 1 was diffusion in the spaces between particles and in the direction of fluid flow. In order to measure a coefficient for this action, it is necessary to provide an appropriate experimental gradient in the axial direction. One way in which this may be done is by passing a single flat concentration or temperature pulse through a bed and measuring the change in wave shape. Although this procedure is relatively simple experimentally, mathematically it is complex. An alternate technique places a greater burden on the experimentalist, but it is relatively more tractable mathematically. The technique is to treat diffusion and reaction problems as analogous to alternating current (electrical) problems. The mathematical methods and theory are transferred from one area to the other. Rosen and Winsche (*6*) at the Brookhaven National Laboratory, through their studies of rate processes in adsorption beds, provided the pioneer investigation in this area. The general field is known as frequency response techniques.

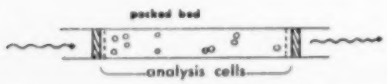

Fig. 5. Apparatus arrangement for frequency-response technique in diffusion measurements.

If the desire is to measure axial diffusion *between* particles and diffusion *within* particles as well by this technique, an experimental arrangement would be effected as shown in Figure 5. A tube packed with the particles is provided with sensing cells for gas analysis placed before and after the packed section. A binary gas mixture, flowing at constant total gas rate, but varying sinusoidally in composition with time, is passed into the bed. The diffusion mechanisms acting in the bed cause a decrease in amplitude and a shift in phase angle of the composition wave as it goes through the bed. Equations have been derived in a study by Deisler (*3*) relating the ingoing and exit composition waves so that from experimental measurements of wave amplitudes and phase angles simultaneously, information may be obtained about three sets of processes: (1) the pellet internal diffusion constant, (*2*) diffusion constant between pellets in the axial direction, and (3) the adsorption isotherm. The major assumption in treating the data analytically is that all processes are linear. This limitation may be circumvented, when necessary, by making the amplitude sufficiently small so that the diffusion constant, say, does not vary appreciably over the range of concentrations swept by the waves.

The system of measurement has the interesting advantage that several processes may be investigated simultaneously, in place, in the final piece of industrial-type equipment, whereas, with older methods, special experimental arrangements would be required to measure adsorption equilibrium and diffusion rates.

It will be recognized that this alternating-current-analogue method of examining a system is not limited to the variables mentioned. Other rate processes could in principle be included when appropriate, such as chemical, or biological rates. The periodic oscillation can be in composition or in any other suitable variable, such as temperature, pressure or flow rate. The frequency response technique in its various forms appears especially promising to the chemical engineer as a means for exploring the dynamic properties of systems that interest him.

Conclusion

These comments about mechanisms and experimental techniques in a limited sampling of reactor technology indicate that the physical rate processes associated with chemical reactors and with the diffusional operations are among the areas of research open to chemical engineers.

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Award address given by R. H. Wilhelm at the A.I.Ch.E. Forty-fifth annual meeting held in Cleveland, Ohio, Dec. 7-10, 1952.

We Talk To Ourselves Too Much!

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No person or group has as much that is vital to tell people today as our scientists, yet no one could be quite as futile as we are in telling it. We seem to lose our imaginations when we try to relate what we are doing with the broad and deep problems that disturb people; and our telling lacks the conviction that alone can persuade people to use what our efforts provide. As a result American chemists, chemical engineers and the chemical industry are pilloried as money grubbers, as mass poisoners, as warmongers, and as all manner of evil beings. Yet they provide the sulfa drugs, the antibiotics, the hormones, an abundance of new and better anesthetics, hypnotics and pain relievers, and many other medically used and useful materials. Today the combined effect is to give each American a present every year of an extra 5.4 months of life; that is the time added to the average American's life span during each of the past ten years. We have gained a new knowledge of human diet that has been estimated to prolong the useful, active period of human life by more than a dozen years. Yet the persons who have provided all peoples with these unparalleled benefits are just now under serious attack from many directions because they put "chemicals" (of all things) into our foods.

During the past several decades the power of chemistry and chemical industry to accomplish good for the people of this sorely troubled world has grown continuously greater. But always we have thought that this tremendous force would reach its full effect only on people in the future, somewhen beyond today. We have recognized in a general way that our responsibilities have been growing with our abilities; but we have assumed that the task of putting to use what we have produced, of interpreting it in human terms, belongs to someone else, that we have fulfilled our mission when we have made products, shown how they can be used for benign purposes, and turned out quantities great enough so that everyone can be supplied with them. There is grave danger in that idea that even we may lose entirely our perspective on what we are doing, and that no one else will be interested enough to do that part of our job for us. We could lose our ability to understand what we are about in terms of its broad effects and certainly our ability to communicate it to others. Thus we may come ourselves to believe in the caricatures of science and scientists that prevail in the comics.

Perhaps it is inherent in our scientific attitude that we cannot make clear to other people, who know nothing of our specialties, the implications and consequences of what we do. It is even highly probable that we ourselves cannot vision the full consequences of our acts. We can progress scientifically only if we concentrate on a miniscule area over a rather long period of time. We must focus sharply on limited objectives if we wish to succeed in solving problems, industrial or scientific or any other, by the scientific method. Indeed, we have developed the whole world of science by this method of systematic concentration on a limited subject with careful exclusion of everything else.

If this concentration of our attention has led to fruitful results, it has not helped people to understand us as scientists or what we have striven to accomplish. The late Gilbert K. Chesterton had this to say on the subject:

D. H. Killeffer

D. H. Killeffer is the dean of public relations men in the chemical field. But, by the use of the title "Dean," the editor does not wish to indicate austerity or age, but to indicate long years of service and usefulness to our profession. D.H.K., as he is known to us, began his writing career back in 1920.

Killeffer is one of the members of that earliest trio of experts in chemical public relations which included Harrison Howe, who built up the American Chemical Society News Service, and "Judge" Grady, who interpreted the chemist to the layman, back in the past when telling John Q. Public about the wonders of the test tube was a brand new and exciting idea.

At present, D.H.K. is consultant with chemical firms on public relations affairs, and writing another book in a series which includes, "Eminent American Chemists"; "The Genius of Industrial Research"; "The First 150 Years," and, as co-author, "The Chemistry of Molybdenum."

Men find it extremely difficult to believe that a man who is obviously uprooting mountains and dividing seas, tearing down temples and stretching out hands to the stars, is really a quiet old gentleman who only asks to be allowed to indulge his harmless old hobby and follow his harmless old nose. When a man splits a grain of sand and the universe is turned upside down in consequence, it is difficult to realize that to the man who did it, the splitting of the grain is the great affair, and the capsizing of the cosmos quite a small one. It is hard to enter into the feelings of a man who regards a new heaven and a new earth in the light of a by-product.

Even when we allow for a certain literary license, Mr. Chesterton's view fits a good many members of our own profession.

That is the reason that we, like all other people who have some specialty in common, prefer to talk endlessly to our own kind, to talk as it were only to ourselves. This fault we share with all humanity. Just as fishermen much prefer the company and conversation of fishermen, or golfers, of fellow addicts of the sport, and mothers, of other mothers, so surely scientists can be forgiven if they prefer to associate with and talk to other scientists. As the special topics of group interest become more abstruse, so does this inclination grow and with that the ability to explain to outsiders shrinks. Far too often we criticize others for not understanding us when we are to blame for not explaining.

Our fault lies in having concentrated too vigorously and on too small objectives. Our tendency has been to learn everything possible about a continuously shrinking area of interest until we approach as a limit infinite knowledge about nothing at all. This differs diametrically from the thinking and point of view of people generally. They consider the whole broad mosaic of human affairs, interests and desires.

These two points of view are related in about the same way as a microscope and a telescope. The obvious facts are that both instruments use lenses to focus light in certain ways and that looking through either instrument in the wrong direction gives an awkward suggestion of the performance of the other. Otherwise the two instruments are quite antithetical. The microscopist concentrates his attention on the narrowest possible field and his instrument enlarges the tiniest objects to occupy his whole vision. On the other hand, a telescope brings into range of vision everything within the widest possible radius.

This divergence between scientists and the public is a deep and fundamental difference and on it rests the common attitude of introvert shyness that scientists assume in public. It points up the need for scientists to take the initiative in creating a general understanding of their doings and the implications growing from them. The pronounced difference in point of view encourages, even compels, scientists to seek their own company in order to get opportunities for self-expression, opportunities to cast off restraint.

All experts think in generalizations and particulars that are peculiarly their own and that are strange to other people. These unique conceptions require a language adapted to specific purposes and hence intelligible only to experts trained in that view, idea and the technique that it is designed to express. In a certain sense the effect of this, although not its purpose, is reminiscent of the days and practices of the ancient alchemists. There are important similarities but there are also vital differences. The cryptic language of the writings of the alchemists served the important purpose of protecting the initiated from persecutions. This it did by hiding meanings. Today's somewhat similar scientific quasi-secret codes presumably stem

Money grubbers . . . mass poisoners . . . warmongers . . .

from the exact opposite cause—the desire of specialists to make themselves exactly understood. Decidedly they are not designed to hide meanings. In spite of that, scientists are surely losing the power to converse with other men, their touch with *genus homo*, by this means.

Our inclination is to think that ideas are and should be principally communicated in erudite and virtually unreadable papers embalmed in "The Literature." Too, we always capitalize "The Literature" in our thinking and often put it all in capitals, which increases its sacrosanctity and minimizes its readability.

The only way that we can make the Literature fulfill its real purpose, to communicate ideas to other people, is to aim what we have to say to the level of information, understanding, and interest of those we plan to reach. Uncommunicated thinking has no practical, ascertainable value, and communication is utterly impossible without an effective receiver as well as a transmitter. Can you imagine anything more futile, for example, than asking a jeweler for a couple of hundred milligrams of crystalline element number 6? By the time you asked his advice about whether to mount it in element number 47, 78 or 79, he would be sure that you had no brains and no idea of buying a diamond in a silver, platinum or gold setting!

Often we excuse ourselves for some of the monstrous dissertations we perpetrate by believing, and no doubt at all with the utmost sincerity, that only in such abstruse terms and language can we possibly express "absolute truth." But even this high-minded thought cannot excuse the consummate bad manners of some such presentations.

Scientific papers generally are written and presented for the particular benefit of the small circle of people who are expert in the author's specialty. It is easier to write for them for the author can take much for granted. It is unnecessary to sketch in the background if one's audience knows it, and it may be possible to leave out a great deal of thinking because the selective audience will enjoy doing its own thinking rather than listening to what someone has thought out for them. The rest of the uninitiated are expected to bow down before a mystery that, in the mystifier's mind at least, is manifestly beyond our understanding. Far from bowing down in reverence at such a performance, I, for one, feel that the editor should have returned the paper to its author and insist that he make his thoughts understandable at least to the average reader. If it is essential that a scientist prepare a recondite, abstruse account at least let him think out his ideas so clearly that he can also prepare a paper that will make anyone understand, even those who studied at different times and in different institutions from his own.

Chemical literature is the same as any other form of self-expression. It must be aimed at an audience and must contain all the information necessary for one to understand its message. You as author must carefully present your material with enough detail and enough background so that those you need to reach can understand what it is about. Scientists, accustomed to talk to each other, habitually violate the old basic rule of expository writing "Never underrate your readers' intelligence nor overrate their information."

We are likely to miss vital parts of the communication of chemical ideas if we confine our definition of chemical literature only to papers, books and journals that might properly be treasured in a scientific library. Labels, directions

for using chemical products, packages, advertisements, popular articles and all the ways that we disseminate information about chemicals and chemical products are all vital parts of the chemical literature. Each of them is part of the information that represents us to the people; each of them is an essential part of our job, but a part that we too often neglect, or do poorly.

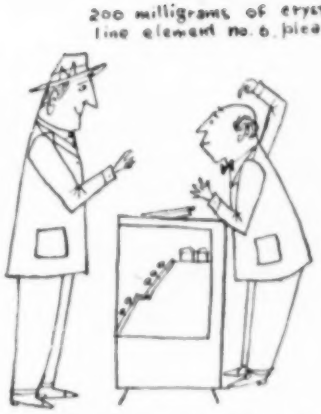
Clearly there are many ways that we can, and often do, misunderstand and mistreat our audience, people generally. Sometimes we do this deliberately, but far more often through ignorance of the obvious need for someone to interpret what we are thinking in terms our audience can understand. We cannot satisfactorily do this ourselves for the simple and compelling reason that we, like other people, like to talk to others who do the same things, who think about the same things in the same ways, and who have the same interests as our own. Our strange language is hard for other people to understand. We think of things in a different way from most people. That is necessary if we are to achieve our ambitions. But it also makes trouble when we try to tell other people what we are doing and how it will affect our joint future.

Caricatures of science and scientists that prevail in the comics.

Scientists, and especially chemists, view things as it were from the other side of the mirror. Which is the main aim and which the by-product? Chesterton died too soon to know how accurately his figure of speech quoted above fits the reality of atomic fission. His harmless old man wanting only to be let alone with his harmless old hobby hardly fits the reactions of scientists to this world-upsetting trifle. Fear of the consequences of their acts forced scientists to try to warn all men of the peril should this force come under the control of men of ill will. These attempted warnings could not fully succeed for our colleagues had trouble getting away from their first basic thought that the main affair was to split atoms and that idea made the bomb a mere by-product. Whenever we try to explain our actions and thoughts to others the opposite points of view of scientists and laymen get in the way of understanding.

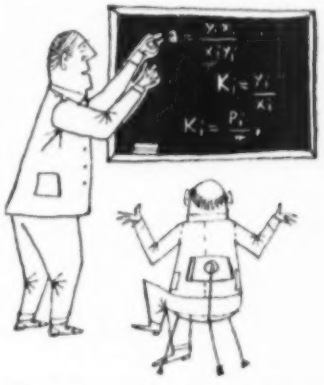
The probable consequences of nuclear fission have forced both scientists and laymen alike thus to focus attention on their differences of view. Thousands of other lesser discoveries and developments possess an aggregate effect likely to be greater in its potential impact on living.

All of this imposes a serious responsibility on scientists that they are not now adequately shouldering. Our relations with the general public have become deplorably tangled. We seem determined to pursue our own ways secure, as we



Can you imagine anything more futile than asking a jeweler . . .

think, in our belief in the rightness of our aspirations. We constantly justify ourselves and our actions by passing on to someone else the responsibility for adapting and justifying the results of our inquiries and our discoveries. Only the immaturity of our thinking persuades that the problem of our relations with the world is the problem of that world, and none of ours. It is a point of view tenable only when we talk to ourselves —too much. Only when we isolate ourselves behind the fancied curtain and security of our own peculiar thinking and language, can we maintain such a feeling of irresponsibility. We cannot, we must not neglect our responsibility to explain our actions for the benefit of all people and to help them to use wisely and well what we provide.



Our strange language is hard for other people to understand.

CHEMICAL RESISTANT CEMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and ROBERT H. STEINER

The Atlas Mineral Products Co., Mertztown, Pa.

SILICATE CEMENTS: Chemically setting silicate cements are prepared by mixing silicate of soda solution with a graded silica containing a setting agent. Slow-setting premixed cements which harden through the evaporation of water only are also available.

APPLICATION AND REMARKS: Silicate cements are applied by trowel in the same manner as Portland cement mortar and are used for joining of acid brick. Silicate cement-joined brickwork is used to protect steel or concrete in floors or stacks subjected to strong oxidizing agents over a wide-temperature range. A typical chemically setting silicate will have a working life of 35 min. and a setting time of 36 hr. These cements are resistant to all inorganic acids and salts (except fluorides), and most organic solvents. Because of their high porosity and solubility in alkaline solutions, they are not recommended for use in the processing of crystallizable salts or at a pH above 7. The information in the corrosion-resistance table should be used discreetly. The lack of chemical attack under specific conditions should not be construed as a recommendation. In general, silicate cements are used only where no other less porous cement is satisfactory.

CHEMICAL COMPOSITION: Chemically setting silicate cements consist of a sodium silicate solution with an sp.gr. of 35-40° Baumé and a Na_2O to SiO_2 ratio of 1:3.2-3.9. A small amount of a chemical setting agent such as Na_2SiF_6 is present in the graded silica filler.

TEMPERATURE LIMITATIONS: Silicate cements are recommended for use in the presence of inorganic acids (except hydrofluoric) at temperatures up to 750° F. Physical properties of these cements decrease rapidly as the temperature approaches 1000° F. Vitrification takes place around 1400° F.

A TYPICAL SILICATE CEMENT

PHYSICAL AND MECHANICAL PROPERTIES

Tensile Strength, lb./sq.in. @ 75° F.	350
Tensile Strength, lb./sq.in. @ 500° F.	300
Tensile Strength, lb./sq.in. @ 750° F.	250
Tensile Strength, lb./sq.in. @ 1000° F.	50
Compressive Strength, lb./sq.in. @ 75° F.	2500
Adhesion to Wire Cut Brick, lb./sq.in @ 75° F.	100
Density	2.0
Water Absorption, %	8-15

CORROSION RESISTANCE

	C	H
ACIDS		
Acetic, 10%	E	E
Acetic, glacial	E	E
Benzene sulfonic, 10%	E	E
Benzoic	E	E
Boric	E	E
Butyric	E	E
Chloroacetic	E	E
Chromic, 10%	E	E
Chromic, 50%	E	E
Citric	E	E
Fatty Acids (C8 and up)	N	N
Fluosilicic	E	E
Formic, 90%	E	E
Hydrobromic, 40%	E	E
Hydrochloric, 37%	E	E
Hydrocyanic	E	E
Hydrofluoric	N	N
Hypochlorous	E	E
Lactic	E	E
Maleic	E	E
Nitric, 5%	E	E
Nitric, 20%	E	E
Nitric, 40%	E	E
Oleic	E	E
Oxalic	E	E
Perchloric	E	E
Phosphoric, 85%	E	E
Picric	E	E
Stearic	E	E
Sulfuric, 50%	E	E
Sulfuric, 70%	E	E
Sulfuric, 93%	E	E
Oleum	E	E
Mixed Acids, 57% H_2SO_4 20% HNO_3	E	E
ALKALIES		
Ammonium Hydroxide	N	N
Calcium Hydroxide	N	N
Potassium Hydroxide	N	N
Sodium Hydroxide	N	N
ACID SALTS		
Alum or Aluminum Sulufate	E	E
Ammonium chloride, nitrate, sulfate	E	E
Copper chloride, sulfate	E	E
Ferric chloride, sulfate	E	E
Nickel chloride, sulfate	E	E
Stannic chloride	E	E
Zinc chloride, sulfate	E	E
ALKALINE SALTS		
Barium sulfide	N	N
Sodium bicarbonate	F	N
Sodium carbonate	N	N
Sodium sulfide	N	N
Trisodium phosphate	N	N
NEUTRAL SALTS		
Calcium chloride, sulfate	E	E
Magnesium chloride, sulfate	E	E
Potassium chloride, sulfate	E	E
Sodium chloride, sulfate	E	E
GASES		
Chlorine, dry	E	E
Chlorine, wet	E	E
Sulfur dioxide, dry or wet	E	E
ORGANIC MATERIALS		
Acetone	E	E
Alcohol, methyl or ethyl	E	E
Aniline	F	N
Benzene	E	E
Carbon Tetrachloride	E	E
Chloroform	E	E
Ethyl Acetate	E	E
Ethylene Chloride	E	E
Formaldehyde, 37%	E	E
Phenol, 5%	E	E
Refinery Crudes	E	E
Trichloroethylene	E	E
PAPER MILL APPLICATIONS		
Kraft Liquor	N	N
Black Liquor	N	N
Green Liquor	N	N
White Liquor	N	N
Sulfite Liquor	G	G
Chlorite Bleach	N	N
Alum	E	G
PHOTOGRAPHIC INDUSTRY		
Developers	G	F
General Use	G	F
Silver Nitrate	G	F
FERTILIZER INDUSTRY		
General Use	F	F
STEEL INDUSTRY		
Sulfuric Acid Pickling	G	F
Hydrochloric Acid Pickling	G	F
Sulfuric Acid-Nitric Acid Pickling	G	F
TEXTILE INDUSTRY		
General Use	G	F
FOOD INDUSTRY		
General Use	F	F
Breweries	F	F
Dairies	F	F
MISCELLANEOUS INDUSTRIES		
Plating	G	F
Petroleum	G	F
Tanneries	G	F
Oil and Soap	F	N
Water and Sewer	F	F

RATINGS:

E—No attack.
G—Appreciably no attack.
F—Some attack but usable in some instances.
P—Attacked—not recommended.
N—Badly attacked.
C—Cold—75° F.
H—Hot—750° F. or boiling point of composition.

No. 19

The Indians had a word for it

TORONTO

—a place of meeting

Article written by G. A. Purdy

Toronto will be the meeting place of the first joint conference of the American Institute of Chemical Engineers and the chemical engineering division of the Chemical Institute of Canada, scheduled for April 27, 28, and 29 at the Royal York Hotel. Toronto, in the Huron Indian language, means "place of meeting." It is well named, particularly when it is a place of meeting for engineers and industrial executives, because it is in Toronto that the most diversified and fast-growing industrial developments in the world are concentrated. This city is also of interest because it is the home of the University of Toronto and the site of leading financial institutions, represented by the Toronto Stock Exchange and head offices of five of Canada's ten chartered banks. Its technical developments have ranged from the electron microscope to the world's most powerful jet fighter and this continent's first jet airliner. Here also were developed important chemicals ranging from insulin to RDX, an explosive used advantageously in World War II. It has been said that the last century belonged to the United States and that the next century belongs to Canada. Whatever the Canadian development may be, Toronto is its spearhead.

Toronto is the capital of the Province of Ontario and is Canada's second largest city. Located on the north shore of Lake Ontario opposite the Niagara River, it is approximately equidistant from Chicago and New York. In bilingual Canada, Toronto is the English-speaking center of the country; its people are largely of Scottish and English extraction.

Early in the eighteenth century when the French and English were warring for control of the fur trade, the French built a fortified trading post on the site of Toronto which they named Fort Rouille. It was burned in 1759 to prevent the British from occupying it. Lord Dorchester made a personal inspection of Toronto in 1793 and pronounced it his choice for the site of the new capital of the Province of Upper Canada, now known as Ontario. That same year Governor John Graves Simcoe changed the name to York and so it remained until 1834, when Toronto was incorporated as a city. Toronto's first mayor was William Lyon Mackenzie, the rebel grandfather of the late Rt. Hon. W. L. Mackenzie King, Prime Minister of Canada.

In those days, the area around King and Yonge Streets was the important business area and remains one today. Here will be found Canada's largest department stores, the Toronto Stock Exchange, the largest bank building, the tallest bank building, and the largest hotel in the British Commonwealth.

While the center of Toronto's business district remains where it was more than 100 years ago, it has, of course, grown greatly in size as has the city of Toronto itself. Almost all of the 40 square miles which comprises the city of Toronto is now occupied, with the result that the city has long since spilled over into a dozen adjoining municipalities. These make up Greater Toronto, population of which is considerably more than one million people. The population is leaving the crowded city and moving to the suburban municipalities. Toronto's peak population was reached in 1946 when 696,555 people lived within the city limits. With longer distances to travel, commuters strained the existing transportation systems and in 1949 Toronto began Canada's first subway, which will begin operating in 1953 and will have a capacity of 40,000 passengers an hour instead of the present Yonge Street surface system's 14,000. The cost is estimated at $40 million.

The swift growth of the city has been more than matched by the development of Toronto as a port—and as a man-made port at that. Forty years ago the waterfront had no dock with more than 14 feet of water. A waterfront area east of the city known as Ashbridge's Bay was a wasteland of swamp. The Toronto Harbor Commission was set up in 1911 and work was started the following year. Since that time the Commission has been responsible for building nine miles of modern docks and on them private firms have built grain elevators with a capacity of 7½ million bushels, cold-storage plants, warehouses and transit sheds.

The Ashbridge's Bay swamp is gone and in its place is the heavy industrial section of the eastern harbor terminals. At the western end of the harbor development is Sunnyside amusement area with its bathing pavilion, sheltered beach behind the breakwater, midway and

board walk. Future expansion of waterfront plans calls for an extension of the eastern terminals out into the lake, and a new breakwater to shelter the proposed docks.

Toronto is Canada's third ranking port and of course is the nation's first lake port. Cargo tonnage handled in 1912 was 343,000. In 1942 it was more than 10 times that amount and last year an estimated 4½ million tons were handled inward and outward.

Toronto is rapidly losing its reputation as the place where a visitor would say he spent a week one Sunday afternoon. Although theatres and bars remain closed, sports events are permitted during the afternoon hours.

On Sunday, too, sightseers can view city hall, with its 300-ft. tower, the Ontario parliament buildings in Queen's Park or Casa Loma, a turretted dream castle which is a show place by day and a ballrom at night. Set on a hill overlooking the city, it was built on a grand scale.

Toronto has thirty-two golf courses, 205 tennis courts, 118 skating, nineteen hockey and four curling rinks, thirty-six bowling greens, sixty-nine baseball fields, forty-one football fields and even ten cricket fields. Its best known sports centers are Maple Leaf Gardens, where National Hockey League games are played, and Maple Leaf Stadium, where Toronto's baseball team plays its home games. Two teams represent the city in big-league rugby.

The city has some 515 organized church bodies; seventeen libraries; monuments and memorials too numerous to record here. The Royal Ontario Museum is the largest in the British Commonwealth outside of London, England. The Art Gallery contains the second largest collection of Canadian paintings in the world, the largest being in Ottawa's Canadian National Gallery.

The University of Toronto is one of the Empire's largest, with 18,000 daytime students and 12,000 more in the evening classes. The city has had its own symphony orchestra since 1894.

Toronto's biggest annual show is the Canadian National Exhibition, which is housed in a $21 million park fronting on Lake Ontario. The Royal Winter Fair, a colorful horse and livestock show, is held in the exhibition's Coliseum and attracts thousands of people each night the show runs. The Exhibition grounds also house the International Trade Fair, which draws exhibitors from all over the world.

Toronto has more than 400 restaurants, some of them specializing in French, Danish, Italian, Chinese, Jewish and Indian food.

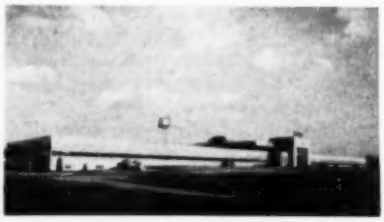
There is only one theatre for stage presentations on a large scale, but the city has motion picture houses in practically every district. Three buildings are used for large concerts, symphony orchestras and the like.

This aerial view shows part of Toronto's man-made harbor. The large building, center left, is the Royal York Hotel, where the joint conference will be held in April. In the center is the city's financial district, dominated by the Bank of Commerce tower, the tallest building in the British Commonwealth.

Where this continent's first jet airliner and most powerful jet fighters were developed and built—A. V. Roe, Canada, Ltd., at Malton, near Toronto.

In the provincial Parliament Buildings, shown here, laws are made for nearly 4¾ million people who live in the province.

In venerable Osgoode Hall, Ontario's higher courts sit. Osgoode is also a training school for young Ontario lawyers.



The International Business Machine Co., Ltd., one of many plants constructed in mushrooming industrial Toronto.

Detroit has automobiles, Pittsburgh has steel, Chicago has stockyards, but Toronto has everything. Almost 90% of all the types of goods manufactured in Canada are included in Toronto's production. The great diversification provides an economic stability greater than is usual in one-industry areas. More than 4,300 plants operate in the Toronto area with an average of only forty-two employees each. The development is thus along the lines of industrial New England rather than in terms of Willow Run. Many of the plants, however, are large. For example, the world's largest agricultural implement manufacturer has his headquarters and some of his plants in Toronto, and nearby an automobile assembly plant with 32 acres under a single roof is being constructed. Many plants on sites ranging from a few acres to more than 400 are in the course of construction at the moment with an estimated value of approximately $100,000,000.

More than 400 United States and United Kingdom branch plants are operated in the Toronto area, the largest concentration of branch operations of outside origin in any city in the world. Consequently, Toronto is a meeting place of engineering skills, industrial experiences and technical know how from all parts of the English-speaking world. It is a logical place for members of the A.I.Ch.E. and C.I.C. to meet.

Plant Tours for Chemical Engineers and Executives

The variety of plants suitable for plant visits is also an important factor. Arrangements have been made for those attending the conference to visit plants not only in the Toronto area but in the Hamilton and Niagara Falls areas.

The tours are as follows:

Tour No. 1. A. V. Roe, Canada, Ltd., Malton. Limited to 35 persons. Wednesday, April 29.

This company manufactures the Canadian-designed Orenda axial turbo-jet engine and air frames for the CF-100 fighter and jet-liner. Note: Request to visit this plant must be forwarded to G. A. Lowles, chairman, Plant Visits Committee, c/o The International Nickel Co. of Canada, Ltd., before March 10, 1953, to obtain necessary clearance.

Tour No. 2. Colgate-Palmolive-Peet Co., Ltd., Toronto. 25 King Street West, Toronto. Limited to 70. Wednesday, April 29.

Modern manufacturing and packaging of soaps, glycerine, detergents and toilet articles.

(*Continued on page* 30)
(*Technical Program on page* 20)

TYGON

Versus $C_{17}H_{33}COOH$

OLEIC acid and the other fatty acids have many uses. By the same token, they also can represent many problems in the fight against corrosion. Particularly at high temperatures, under aeration, or in combination with other chemicals do they prove troublesome.

There are a number of materials which offer protection against oleic acid. Among them is the TYGON family of plastic compounds. However, the satisfactory use of TYGON compounds against oleic acid depends upon their proper use — upon the realization of the limitations of organic resins and plasticizers in contact with organic acids.

The TYGON family consists of a number of standard and special compounds based on a series of selected vinyl resins which are skillfully modified with other materials to give the maximum in resistance to acids, alkalies, oils, greases, water and most solvents. They are also designed to give the best balance of chemical resistance with desirable physical, mechanical and electrical properties. For further versatility, TYGON is made available in the forms of calendered or press-polished sheeting, molded goods, extrusions, paints and plastisols.

Against the oleic acid, the resistance and performance of TYGON, in any of its forms, depends primarily upon the concentration of the acid and the service temperatures involved. At low acid concentrations and low temperatures, the resistance and performance of TYGON are excellent. However, as concentration or temperature increase, definite changes take place. If both are increased, the apparent limits are full concentration at 125°F. Beyond this point, the protectability of TYGON is relatively unaffected, but physical changes limit its performance. Pronounced hardening and stiffening gradually take place, along with a noticeable color change. Thus, at high temperatures, the efficiency of TYGON is reduced with time and concentration.

Where mixtures of oleic acid and other chemicals are encountered, the resistance of TYGON varies according to the nature of the other chemicals present. It is difficult to estimate the degree of protection offered, without full knowledge of the existent conditions. Previous testing or the counsel of U. S. Stoneware engineers is strongly recommended.

In general, TYGON safely handles oleic acid at the concentrations and temperatures normally encountered in its use. Only the extreme cases require special consideration. In addition, the variety of compounds and the different forms available give TYGON wide application.

As calendered or press-polished sheeting, TYGON is used to line and cover all types of process equipment. It also is die-cut in positive and enduring gaskets, seals, and separators.

As molded goods, TYGON is also used for gasketing, but has many other uses which are limited only by the size and shape that can be imparted to a thermoplastic material by mold and press.

As extruded tubing (in sizes up to 2" ID), TYGON finds many uses in both plant and laboratory. Its clarity, flexibility, light weight, and high strength greatly speed and simplify the transmission of corrosive liquids, gases and semi-solids. Extruded solid cord and channel are also used as gasketing, expansion jointing, and packing.

As a paint, TYGON protects equipment and plant against corrosive fumes and spillage. As a plastisol, TYGON is used as a heavier duty coating or in the manufacture of flexible parts and fittings.

If you have fatty acid, or any chemical, corrosion problems, look into TYGON. It may well be the sure, simple, economical answer.

TYGON plastics

In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling oleic acid and other fatty acids in any concentration and under all types of operating conditions. These products include chemical stoneware and porcelain, acid proof brick and cements, homogenous lead linings, and other organic linings and coatings.

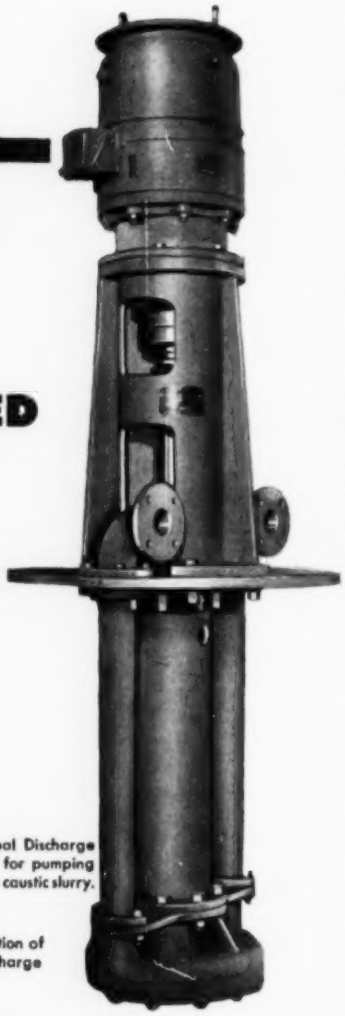
Why don't you submit your corrosion problem today? There's no obligation and we'll be pleased to be of assistance. So write, now!

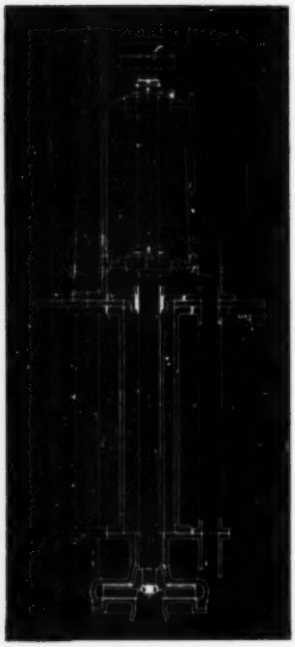
630

THE UNITED STATES STONEWARE CO., Akron 9, Ohio

ENGINEERS, MANUFACTURERS, ERECTORS OF CORROSION-RESISTANT EQUIPMENT SINCE 1865

VERTICAL PUMPS WITH NO SUBMERGED BEARINGS FOR PUMPING ABRASIVE CORROSIVE SLURRIES



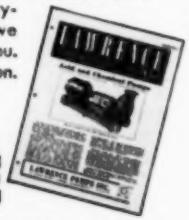


2" Dual Discharge Pump for pumping molten caustic slurry.

Cross section of Dual Discharge Pump.

This rugged type of service calls for advanced design: — extra heavy shaft, double-ported casing to equalize the side thrust of the impeller, and tough abrasion-corrosion resistant alloys. The dual discharge pump illustrated here incorporates these features and dispenses with bearings or packing below the cover plate where they would be in contact with the liquid.

Difficult pumping problems, particularly in the process industries, have been our specialty for ninety-one years. Perhaps we can be of help to you. Write us — no obligation.



LAWRENCE PUMPS INC.

Write for Bulletin 203-6 for complete summary of acid and chemical pump data.

375 MARKET STREET, LAWRENCE, MASS.

TORONTO MEETING

(*Continued from page* 18)

TECHNICAL PROGRAM

Monday, April 27, 1953

SESSION 1

GENERAL TECHNICAL PROGRAM

9:45 A.M. IMPROVEMENTS IN THE MANUFACTURE OF ALCOHOL FROM SULFITE WASTE LIQUOR DURING THE LAST TEN YEARS—H. G. Joseph, Superintendent, Alcohol Plant, The Ontario Paper Co., Ltd., Thorold, Ont.

10:15 A.M. DECATIONIZATION OF WASTE SULFITE LIQUOR BY MEANS OF AN ION-EXCHANGE RESIN REGENERATED WITH SULFUR DIOXIDE—J. H. E. Herbst, Ontario Research Foundation, Toronto, Ont.

10:45 A.M. ION-EXCHANGE RATE MECHANISM—Herman Bieber, F. E. Steidler, and W. A. Selke, Dept. of Chemical Engineering, Columbia University, New York

11:15 A.M. ION EXCLUSION—COLUMN ANALYSIS—D W. Simpson and R. M. Wheaton, Physical Research Laboratory, Dow Chemical Co., Midland, Mich.

12:15 P.M. Luncheon speech: HYDRO MATTERS OF CONCERN TO ENGINEERS — Robert H. Saunders, Chairman, Hydroelectric Power Commission of Ontario.

SESSION 2

SYMPOSIUM ON CHEMICAL ENGINEERING PROCESSES

2:00 P.M. CANADIAN PROCESS PLANT DESIGN—S. V. Antenbring, Imperial Oil, Ltd., Sarnia, Ont.

2:30 P.M. DISCONNECTS AND INSTRUMENTATION FOR RADIOCHEMICAL PROCESSING—Richard Stephenson, Carbide and Carbon Chemicals Co., Oak Ridge National Laboratory, Oak Ridge, Tenn.

3:00 P.M. TECHNOLOGY OF NEUTRAL SULFITE LIQUOR RECOVERY BY THE SULFOX PROCESS —Arthur Pollak and Robert S. Aries, Sulfox Corp., New York.

3:40 P.M. FLUO-SOLIDS ROASTING OF ZINC CONCENTRATES FOR CONTACT ACID—T. T. Anderson, Assistant Chief Engineer, Chemical Section, Aluminum Co. of Canada, Ltd., Montreal, Que., and R. Bolduc, Supervisor, Fluoride Dept., Aluminum Co. of Canada, Ltd., Arvida, Que.

4:20 P.M. MANUFACTURE OF NITROGLYCERINE BY THE BIAZZI CONTINUOUS PROCESS—H. J. Klassen, Manager, and J. M. Humphrys, Technical Assistant, Development Section, Explosives and Ammunition Dept., Canadian Industries, Ltd., Montreal, Que.

Tuesday, April 28

SESSION 3

SYMPOSIUM ON COMMUNICATION FOR ACTION IN AN ORGANIZATION

9:30 A.M. WRITTEN COMMUNICATION—WHEN, WHAT, AND HOW—A. J. Johnson, Vice-President, Shell Development Co., Emeryville, Calif.

10:15 A.M. ORAL PRESENTATION—TIME TO TALK—John Slezak, President, Turner Brass Works, Sycamore, Ill.

11:00 A.M. SEMANTICS—DO YOU MEAN WHAT YOU SAY?—Gilbert Brighouse, Dept. of Psychology, Occidental College, Los Angeles, Calif.

12:15 P.M. Luncheon speech: ACCOUNTING AS A MEANS OF COMMUNICATION—C. F. Braun, President, C. F. Braun and Co., Alhambra, Calif.

SESSION 4

GENERAL TECHNICAL PROGRAM

2:00 P.M. SCALE MODELS IN CHEMICAL-PLANT DESIGN—F. S. McCarthy, Canadian Industries, Ltd., Montreal, Que.

2:30 P.M. PULSE COLUMNS—Richard Stephenson, Carbide and Carbon Chemicals Co., Oak Ridge National Laboratory, Oak Ridge, Tenn.

3:00 P.M. TWO-PHASE FLUID FLOW IN VERTICAL TUBES—Seymour Calvert and Brymer Williams, Dept. of Chemical and Metallurgical Engineering, University of Michigan.

3:30 P.M. FLUID-PARTICLE BEHAVIOR—Thomas S. Mertes and Harrison B. Rhodes, Sun Oil Co., Marcus Hook, Pa.

6:30 P.M. BANQUET—**Speaker:** H. L. Keenleyside, Director, United Nations Technical Assistance Program.

Wednesday, April 29

SESSION 5

SYMPOSIUM ON RATES OF INTERPHASE MASS TRANSFER

9:15 A.M. MASS TRANSFER BETWEEN TWO LIQUID PHASES—K. F. Gordon and T. K. Sherwood, Dept. of Chemical Engineering, Massachusetts Institute of Technology.

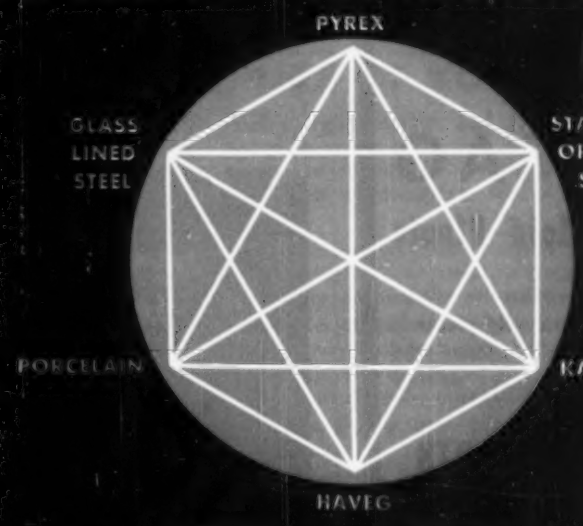
9:45 A.M. LIQUID-LIQUID EXTRACTION IN A SPRAY TOWER—Charles L. Ruby and Joseph C. Elgin, Dept. of Chemical Engineering, Princeton University.

10:15 A.M. SIZE AND MASS-TRANSFER STUDIES ON GAS BUBBLES—B. L. Harris, A. I. Johnson, and C. J. Quigley, Dept. of Chemical Engineering, Johns Hopkins University.

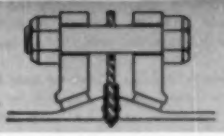
10:45 A.M.—EFFECT OF FLUID PROPERTIES ON GAS-PHASE MASS TRANSFER—E. J. Lynch and C. R. Wilke, Division of Chemical Engineering, University of California, Berkeley.

11:15 A.M. ABSORPTION AND DESORPTION OF SLIGHTLY SOLUBLE GASES IN FALLING LIQUID FILMS—R. E. Emmert and R. L. Pigford, Dept. of Chemical Engineering, University of Delaware.

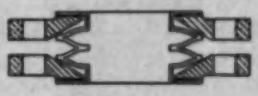
CHEMISEAL MADE OF TEFLON CONNECTIONS



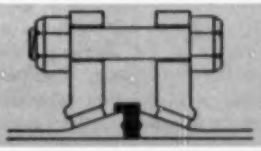
Join All Types of Chemical-Resistant Pipe and Equipment



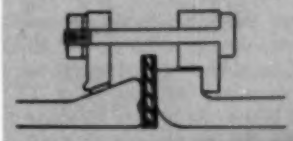
Chemiseal Teflon-Jacketed Gaskets, Types T6N or T6-300 are standard for Corning conical flanges, seal at unusually low bolt loads.



Chemiseal Flexible Couplings No. 202—(Teflon Bellows with two or three convolutions) and Chemiseal Expansion Joints No. 212—(several convolutions), for use in absorbing thermal or mechanical movement and vibration, protecting costly piping. Sizes 1 in. to 12 in. I.P.S. Require no gaskets or adaptors to join unlike piping ends and materials.



Chemiseal Snap-on Type 820 Gaskets. Teflon molded to match contour of conical-end glass pipe, assure perfect centering of joints—free flow of materials. For all standard pipe sizes, ¼ in. to 6 in.



Chemiseal Teflon-Jacketed Adaptors No. 2-CRS, provide a tight, safe seal between unlike piping ends and nozzles. A steel bearing ring provides rigidity. Resilient core assures safe seal at low bolt loads. Teflon Jacket protects and contains easy-to-handle single unit.

UNITED STATES GASKET COMPANY

FLUOROCARBON PRODUCTS DIVISION
CAMDEN 1, NEW JERSEY
Representatives in Principal Cities Throughout the World

BAMAG

BAMAG

Nitric Acid Plants

Before deciding on equipment for nitric acid plants it will pay you to study the worthwhile features offered by

BAMAG PLANTS

1. High nitrogen yield
2. Low power consumption
3. Energy recovery in tail-gas and steam turbines
4. Simple and automatic operation

Consult General Industrial for BAMAG PROCESSES to manufacture:

98-99% Nitric Acid

55-60% Nitric Acid

Ammonium Nitrate

Sodium Nitrate

Ammonium Sulfate

Accessories for fertilizer plants

Consult without obligation

GENERAL INDUSTRIAL DEVELOPMENT CORPORATION
270 PARK AVENUE
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Kaiser Aluminum & Chemical Corp. began bauxite mining operations on the British West Indies Island of Jamaica last month. The first 10,000-ton shipment of the aluminum ore was loaded on the S.S. Evanthia, (see above) and consigned to the company's Baton Rouge, La. plant for processing. The new bauxite facilities were constructed at a cost of 12 million dollars. Bauxite from Jamaica has a haul of 1,100 miles to Baton Rouge, where the company processes all its ore into alumina to supply its primary aluminum plants at nearby Chalmette, La., scheduled for completion in mid-year, and Mead and Tacoma, Wash. Formerly the bauxite was obtained from South America. The new bauxite properties will have an annual capacity of approximately 2,000,000 tons. Approximately 19,000 acres of bauxite reserves, sufficient to supply Kaiser Aluminum's operations for fifty years, have been acquired.

The bauxite is open-pit-mined and hauled in train-load lots by diesel locomotives over 13 miles of private standard-gauge railroad to ore-handling, drying and storage facilities at Port Kaiser, located on the coast at Little Pedro Point. A conveyor belt system automatically loads ore ships anchored at a steel and concrete pier extending 995 ft. out from the shore where there is sufficient water depth to handle all sizes of ocean-going vessels.

ESSO TO EXPAND AT BAYWAY, NEW JERSEY

Esso Standard Oil Co. has awarded a contract for a 60,000 bbl./day crude distillation unit at its Bayway, (N. J.) refinery to The M. W. Kellogg Co. This addition to Esso's production facilities will provide a major increase in the crude capacity of the Bayway refinery, largest on the East Coast. Engineering is underway with erection scheduled to start in early Summer.

1952 RECORD YEAR FOR ALUMINUM PRODUCTION

United States production of primary aluminum during 1952 hit an all-time high. The Aluminum Association disclosed recently. Production of 1,874,642,692 lb. was 34 million lb. above that for 1943, the previous peak year, and 12% higher than the 1951 total. Accelerated production during the last quarter of 1952, amounting to 470,719,231 lb., was responsible for the new record. Despite these figures, member companies in The Aluminum Association reported slight decreases from the 1951 totals in their 1952 shipments of aluminum sheet and plate, foil, and permanent- and semipermanent-mold castings.

A.E.C. TO BUILD EXPLOSIVES PLANT

The United States Atomic Energy Commission has selected a site 18 miles east of Macomb, Ill., on the Spoon River in Fulton County, for a new explosives processing and assembly plant. The new plant will not manufacture radioactive material. Transfer of approximately 9,800 acres of government-owned land on the former site of World War II Camp Ellis, is being made to A.E.C. by the General Services Administration.

Construction of the new plant, to be named the Spoon River plant is estimated to cost about $29,000,000.

In announcing the site selection, Carroll L. Tyler, manager of the A.E.C.'s Santa Fe Operations Office at Albuquerque, N. M., said that a new engineering office to supervise construction will be established soon. W. A. Curtis, chief, production planning branch, Santa Fe Operations Office, has been designated as project engineer in charge of the construction for the Commission.

The Fluor Corp., Ltd., Los Angeles, Calif., is architect-engineer for the project.

(More News on page 26)

Ever ask your **TREASURER . . .**

WHAT *HE* THINKS OF YOUR TANKS?

(A POSEY IRON Bid Might Interest Him and YOU)

Most treasurers are apt to put cost first. And cost is certainly *not* the only factor to consider when buying steel plate construction.

But —

It's good engineering as well as good financial policy to refuse to pay a penny more for tanks . . . or pressure vessels . . . or stacks . . . than is necessary fully to meet *the standard desired.*

The Posey Iron Works offers you 42 years of money-saving experience over the full range of steel plate fabrication . . . *practical* engineering and design service that concentrates on structural integrity and safety rather than on cost-padding "frills".

That's why we say a Posey Iron bid might interest your treasurer as well as you.

Edges of Plates Properly Prepared for Welding . . .
Electrodes Carefully Selected

Perhaps more than any other production step, welding influences tank costs and structural soundness. Every electric welder in Posey's shops is fully qualified. No plate is welded without proper preparation of edges . . . electrodes are chosen after careful consideration of requirements.

Posey meets all standard codes including ASME; API-ASME; API. Consultation does not obligate you.

Posey Iron Works self-supporting stacks installed at the Niagara Falls Plant of the International Graphite & Electrode Division of Speer Carbon Co. Height: 50 ft. Diameter: 3 ft.

AND STEEL AND ALLOY STEEL PLATE FABRICATION

POSEY IRON WORKS, INC.

Steel Plate Division

LANCASTER, PA.

New York Office: Graybar Building

ESTABLISHED SINCE 1910

DIVISIONS
Brick Machinery
Foundry
Industrial Heating
Iroquois
Shipbuilding
Steel Plate

NOW AVAILABLE

Rockwell

GUN LUBRICANT TUBE

Actual size of gun lubricant tube for Nordstrom valves.

BULK LUBRICANT TUBE

Actual size of bulk lubricant tube for Nordstrom valves.

LUBRICANT TUBE KEY

Actual size of key supplied with each tube.

IN TUBES!

FOR LUBRICANT SCREW AND LUBRICANT GUN USE

Lubricauts For Nordstrom Valves

SIMPLEST, CLEANEST, MOST ECONOMICAL METHOD OF VALVE LUBRICATION

The new Rockwell lubricant tubes were developed to provide a better means of lubricating Nordstrom valves. They are a big time and money saver for maintenance departments; a great convenience to supply stores.

For Nordstrom valves equipped with lubricant screws, you just insert tube spout in the valve shank and turn key until lubricant chamber is filled. It's easy and quick! The lubricant is always kept fresh . . . no chance for contamination by dirt or grit. The inventory problem is simplified—one tube fits all sizes and types of Nordstrom valves.

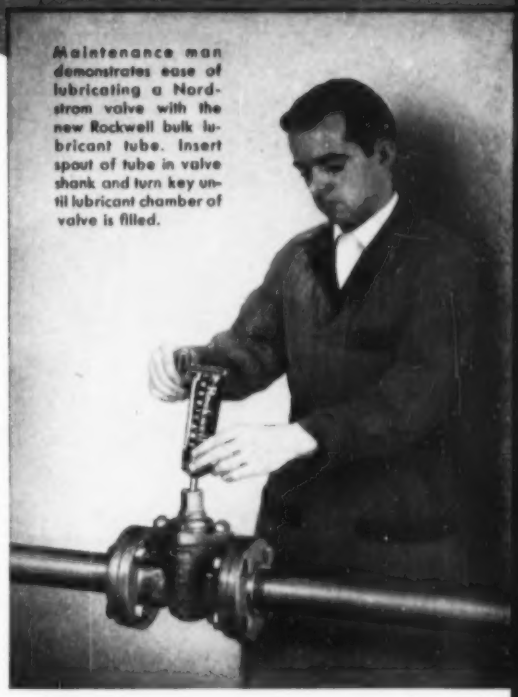
If you lubricate Nordstrom valves by lubricant gun, then specify the new Rockwell gun tube. Insert it in your gun and turn the key until all lubricant has been emptied into the barrel. The whole job takes only a few seconds.

Rockwell bulk lubricant tubes are normally packaged in boxes of four; however, single tubes are also available. Gun lubricant tubes are supplied in boxes of six.

The most commonly used Rockwell Nordcoseal lubricants are now produced in tube, stick and bulk form. Other Nordcoseal lubricants and Hypermatic, the energizable lubricant, will still be available in stick and bulk form.

To assure positive valve closure, quick easy operation and longest valve life, use *only* genuine Rockwell lubricants in Nordstrom valves.

Write for bulletin V-220 describing Rockwell lubricants for Nordstrom valves. Rockwell Manufacturing Company, Pittsburgh 8, Pennsylvania.



Maintenance man demonstrates ease of lubricating a Nordstrom valve with the new Rockwell bulk lubricant tube. Insert spout of tube in valve shank and turn key until lubricant chamber of valve is filled.

Demonstrating the convenience of filling a lubricant gun with the new Rockwell gun tube. Insert tube in gun and turn key until all lubricant has been emptied into the barrel.

ROCKWELL Built
Nordstrom Valves

Lubricant-Sealed for Positive Shut-Off

Another ROCKWELL Product

for *Low*
VACUUM PUMP MAINTENANCE COSTS and BETTER VACUUM . . .
it's the
HILCO OIL RECLAIMER
VACUUM for PUMP USERS . .

Oil Reclaimer

A simple, economical and efficient method of restoring contaminated lubricating and sealing oil to the full value of NEW OIL. The HILCO will produce and maintain oil free of solids, gums, water and gases in a continuous, all-electric, automatic operation.

Be SURE of clean oil in your HIGH VACUUM PUMPS

Specify HILCO OIL RECLAIMER SYSTEMS . .

• *WRITE FOR COMPLETE DETAILS IN THE FREE BULLETIN*

Recommendations at no Obligations

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NEWS

(Continued from page 22)

A MINE OF INFORMATION ON ATOMIC ENERGY

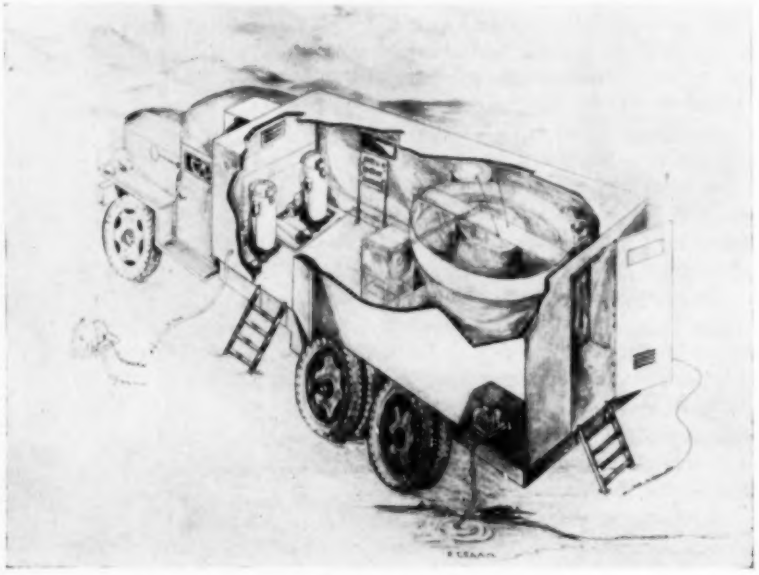
A summary of the U. S. Atomic Energy Program has been put within the covers of a 47-page booklet published by the American Society of Mechanical Engineers and titled "Uranium, Plutonium and Industry." Amply illustrated with photographs of equipment and performance, this review is a revision and an enlargement of a previously published booklet "Catching Up on Atomic Energy," prepared by Vitro Corporation of America. The material has been drawn from open literature and from unclassified or declassified papers and publications of the U. S. Atomic Energy Commission, and has been brought up to date as of Sept. 15, 1952.

Under the heading of production the story covers the program on raw materials, feed materials, fissionable materials, and weapons. Under research and development can be found an account of research in the physical sciences; chemistry and metallurgy; life sciences; reactor development and weapons development. The applications of atomic power are made the subject of study with a consideration of ship propulsion, aircraft propulsion and central station power plants. For the benefit of those who want to know the best sources of information on the atomic energy program the booklet devotes some ten pages to technical literature and A.E.C. depository libraries.

This mine of information, sponsored by the Nuclear Energy Applications Committee of the A.S.M.E., 29 W. 39th St., New York 18, costs $1.50.

MEMBERS ADDED TO LIST ON STATE BOARDS

The list of A.I.Ch.E. members who are playing an important part in the state registration of professional engineers (see "C.E.P." page 44, January, 1953) has two omissions. They are George Armistead, appointed member of the Board of Registration for Professional Engineers of Washington, D. C., whose appointment was referred to in the January issue, page 60, and Frederick K. zur Burg recently appointed to the Louisiana Board by Governor Kennon.



Artist's drawing of the Army's new 3000 gal./hr. mobile water purification unit, developed at the Engineer Research and Development Laboratories, Fort Belvoir, Va. Unit is able to purify available surface water in temperatures ranging from —40° F. to 125° F. The truck contains power and heating facilities, and three men can have it in operation within 45 min. The heart of the unit is a solid contact clarifier known as Erdlator, an all metal up-flow coagulation basin, 7 ft. in diam., and 5 ft. high. Raw water enters the clarifier, is aerated and stirred with chemicals which include the coagulant, alum or ferric chloride, the coagulant aid, pulverized limestone; and the disinfectant, calcium hypochlorite. Flow through the clarification zone permits agglomeration of the precipitates and hydraulic separation of resultant slurry. Coagulation is continuous and is accomplished in 17 min. Slurry is continuously withdrawn by gravity and concentrated externally.

Clarifier effluent is collected in a small wet well and pumped to two diatomite filters connected in parallel. The filter effluent is discharged into collapsible-type fabric tanks, each having a capacity of 1500 gal. Though primarily military, the unit has civilian uses and a ten-week Midwest tour is now under way to demonstrate its application for contaminated water.

4TH ANNUAL SYMPOSIUM NEW JERSEY SECTION

The fourth annual one-day meeting of the New Jersey Section, A.I.Ch.E., will be held at the Essex House, Newark, N. J., on Tuesday, May 5, from 8:30 A.M. to 4:30 P.M. Two symposia will be presented simultaneously at the morning session: one on catalysis, presided over by W. E. Catterall, and one on centrifuging, conducted by C. R. Vander Linden. The afternoon session will be devoted to chemical-project evaluations, with T. S. Leary as chairman. Details of the technical program follow:

Morning Sessions

SYMPOSIUM ON CATALYSIS

9:15—FUNDAMENTALS OF CARRYING OUT CHEMICAL REACTIONS IN FLUIDIZED BEDS by E. R. Gilliland, M.I.T.

10:10—MECHANISM OF MOVING CATALYST AND FLUIDIZED CATALYST PROCESSES by M. Sittig, Ethyl Corp. Research Laboratories, Detroit, Mich.

11:05—PREPARATION OF PHTHALIC ANHYDRIDE BY THE FLUIDIZED CATALYST TECHNIQUE by R. F. Ruthruff, consulting chemical engineer, Homewood, Ill.

SYMPOSIUM ON CENTRIFUGING

9:15—THE PRESENT STATE OF THE THEORY OF CENTRIFUGATION by J. O. Maloney, University of Kansas.

10:10—SCALING UP LABORATORY CENTRIFUGING DATA by C. M. Ambler, The Sharples Corp., Philadelphia, Pa.

11:05—CENTRIFUGING EQUIPMENT: BATCH TYPE by W. C. Crandall, American Tool and Machine Co., New York, and **CONTINUOUS TYPE** by P. Stahl, Centrico, Inc., Englewood, N. J.

Afternoon Session

CHEMICAL-PROJECT EVALUATION

2:30—MARKET RESEARCH AND FORECASTING by Parker Frisselle, Dow Chemical Co., Midland, Mich.

3:00—COST ESTIMATES IN PROJECT EVALUATION by J. H. Boyd, consulting chemical engineer, New York.

3:30—MANAGEMENT'S VIEWPOINT by D. B. Keyes, Arthur D. Little, Inc., New York.

Luncheon will be held at the hotel at 12:15, and there will be a business meeting at 1:45 P.M. Tickets for the luncheon are $3.00. Registration fee for members of the N. J. and N. Y. sections is $3.00; for nonmembers, $4.00; for students, $1.00. Further information about the meeting may be obtained from Charles L. Kroll, E. R. Squibb and Sons, Georges Road, New Brunswick, N. J.

(More News on page 31)

SPARKLER FILTERS

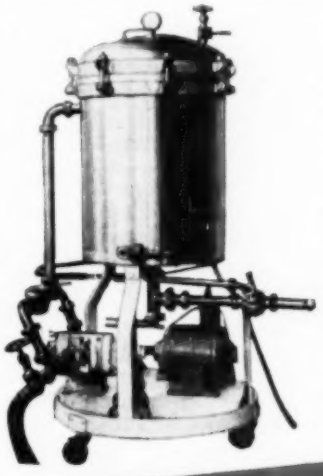
Used by many pharmaceutical manufacturers because of Complete Sanitation

A COMPLETELY SANITARY FILTER

with sanitary piping and fittings

You can see at a glance why Sparkler filter plates are the most sanitary plates ever designed.

All surfaces, inside and out, are easily accessible for thorough cleaning. The top screen that supports the filter paper, a center separator, and the bottom plate is all there is to it. These parts can be separated without unscrewing bolts or nuts. The tie rods of the complete plate assembly holds the plate parts firmly together without danger of bypassing.



With most other types of filter plates the inner surfaces are inaccessible and cannot be cleaned; contaminating particles are locked in and the first run of a new batch frequently must be discarded or rerun through the filter to obtain a pure product.

With Sparkler sanitary plates, a pure product is obtained right from the start, and continues pure with fine sharp filtration to the end of the filtering cycle.

Sparkler filter plates can be removed for cleaning in one unit and a fresh thoroughly clean set lowered into the filter tank. This reduces down time to a matter of minutes.

Sparkler filters are available in stainless steel, monel, nickel, bronze, or Hastelloy, steam or brine jacketed. Available in a range of capacities up to 10,000 G.P.H.

SPARKLER MANUFACTURING COMPANY
MUNDELEIN, ILLINOIS

For personal service on your filtration problems
Write Mr. Eric Anderson

SERVICE REPRESENTATIVES IN PRINCIPAL CITIES

Sparkler International, Ltd.
Prinsengracht 876 Amsterdam, Holland

Sparkler Western Hemisphere Corp.
Mundelein, Ill., U.S.A.

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Valuable Compilation on Styrene

Styrene, Its Polymers, Copolymers and Derivatives. Ray H. Boundy, Raymond F. Boyer, and Sylvia Stoeser. Reinhold Publishing Corp., New York. (1952) XXII and 1304 pp., $20.00.

Reviewed by P. O. Powers, Pennsylvania Industrial Chemical Corp., Clairton, Pa.

A decade ago, stryene was just beginning to find commercial acceptance; now it is one of the leading raw materials for plastics and for synthetic rubber, for paints, ion-exchange resins and a host of other new products. The Dow Chemical Co. developed a most successful process for the manufacture of styrene and has been active in development of many of its derived products.

It is fortunate that several workers at Dow have, with assistance of others, assembled in one volume a summary of our knowledge of styrene. This is not a small book nor is it an inexpensive one; it is a remarkably good compilation of an extensive field.

The first chapter is a brief but adequate history of styrene, and this is followed by a description of methods of manufacture of styrene. There is also a detailed account of German methods for styrene and polystyrene. Alpha methyl styrene, divinyl benzene and halo styrenes, also methods of handling styrene, are each given a chapter. Recent material is added in appendices; vinyl toluene is considered thus. The chemistry of styrene is carefully summarized and methods of analysis are thoroughly reviewed.

The chapters on physical properties of styrene monomer and of polystyrene are particularly useful since the authors have carefully assembled and often tabulated the best values.

The chapters on polymerization of styrene, on molecular weight and solubility, on rheological properties, and copolymerization give a full presentation of the theoretical aspects of these fields.

An extensive survey is presented of styrene polymers and copolymers. The chapter on fabrication of polystyrene is up to date and includes a careful discussion of factors involved in compression and injection molding, methods of forming, and manufacture of bristles, fibers and films, adhesives, and methods of coloring.

The editors have covered the field from the manufacture of the starting material through to fabrication of the finished products from the viewpoint of the engineer, the compounder and the research chemist. This is a useful book to any who are interested in styrene or in a better understanding of the plastics field.

Postgraduate Course in Labor

Manpower Resources and Utilization. A. J. Jaffe and Charles D. Stewart. John Wiley & Sons, Inc., New York; Chapman & Hall, Ltd., London (1951) 532 pp. $6.50.

Reviewed by N. A. Shepard, Chemical Director, American Cyanamid Co., New York.

THIS comprehensive and detailed treatise on manpower and analysis of the factors influencing the supply gains much in authenticity from the fact that one of the coauthors had years of practical experience at the Bureau of Labor Statistics, and the other at the Census Bureau. These experiences flavor the entire book and to a considerable extent account for the highly statistical treatment of the subject.

The book is divided into three parts. Part one is concerned with definition of the working force, as opposed to such terms as manpower, labor supply and population, and analysis of the economically active population. A detailed definition and explanation are given of the terms *employed, inactive-employed, unemployed* and *inactive-unemployed*, with statistics on the past trends and current situation in relation to the military partial mobilization. The value of working-force data in the present emergency is emphasized and the serious problems to be solved are pointed out. The authors ask if the Armed Services should not be required to review their standards for rejection, re-examine how effectively they use the manpower under their control and consider ways of utilizing all persons within the military service, whether or not they meet traditional physical standards set for inductees; and what criteria can be agreed upon for allocating manpower between civilian and military uses.

They point out the effect on the present manpower situation of the slump of births during the 1930's and the increase in the number of persons more than 65 —of more than 2½ million since 1940— and the effect of this increase on the basic civilian requirements of this group which is largely out of the working force and nonproductive.

Statistical description of the American working force, both past and present, is the subject matter of Part II, as regards age and sex, color, urban and rural, family characteristics, marital and dependency status, occupational distribution and seasonal variation. Engineers will find the statistics on the emergence of the highly skilled white-collar technician and scientist of considerable interest (page 194). It is stated that in 1870 some 9,000 persons altogether were reported as engineers (all classifications) while the number in 1940 had increased to 449,000 (a 50-fold increase). There is also an interesting section on the retirement of men from the working force—rates by age and by occupation.

Finally, in Part III, factual data are presented on the relationship between the working force and technological, demographic (personal) and social factors of society; includes data from various other nations. There is a section (page 241) on the growth and nature of inventions which is of special interest to the scientist and engineer, and the effect of inventions on productivity and leisure, and the implications in employment and unemployment.

There are ten appendices, an extensive bibliography and a good index. The development and mechanization of the tobacco processing and manufacturing industry are the subject of one of these appendices and it presents an interesting case history of the effect of mechanization on manpower requirements.

As an advanced text for a labor and labor relations specialist, the reviewer recommends this book; also, as a reference book for engineers particularly concerned with labor problems.

Books Received

Advanced Mechanics of Materials (Second ed.). Fred B. Seely and James O. Smith. John Wiley & Sons, Inc., New York (1952). 680 pp. $8.50.

Quantitative Analysis. Elementary Principles and Practice. Harvey Diehl and G. Frederick Smith. John Wiley & Sons, Inc., New York (1952). 539 pp. $5.00.

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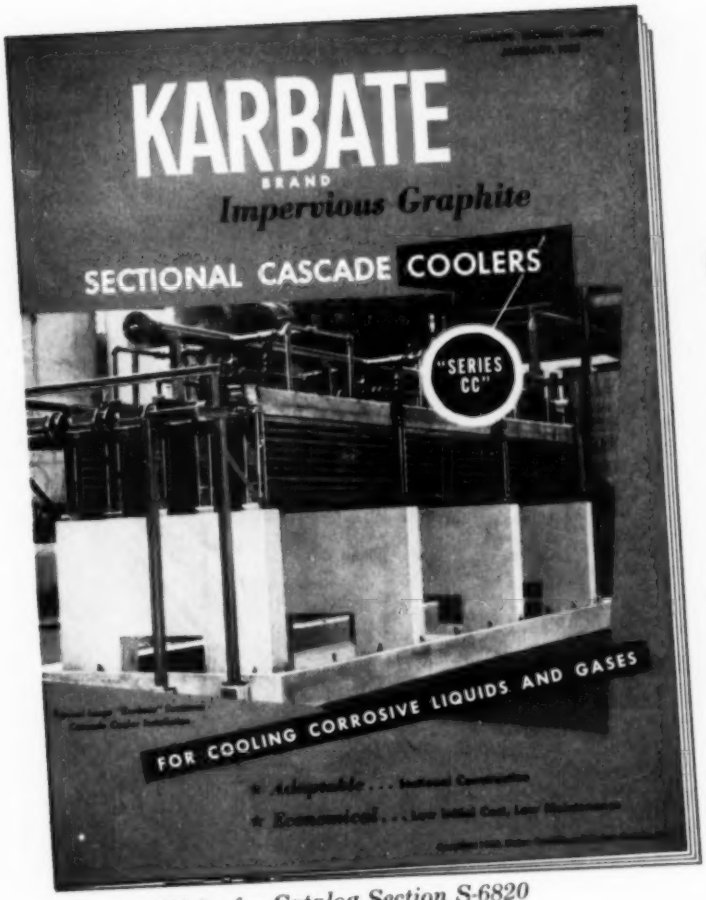

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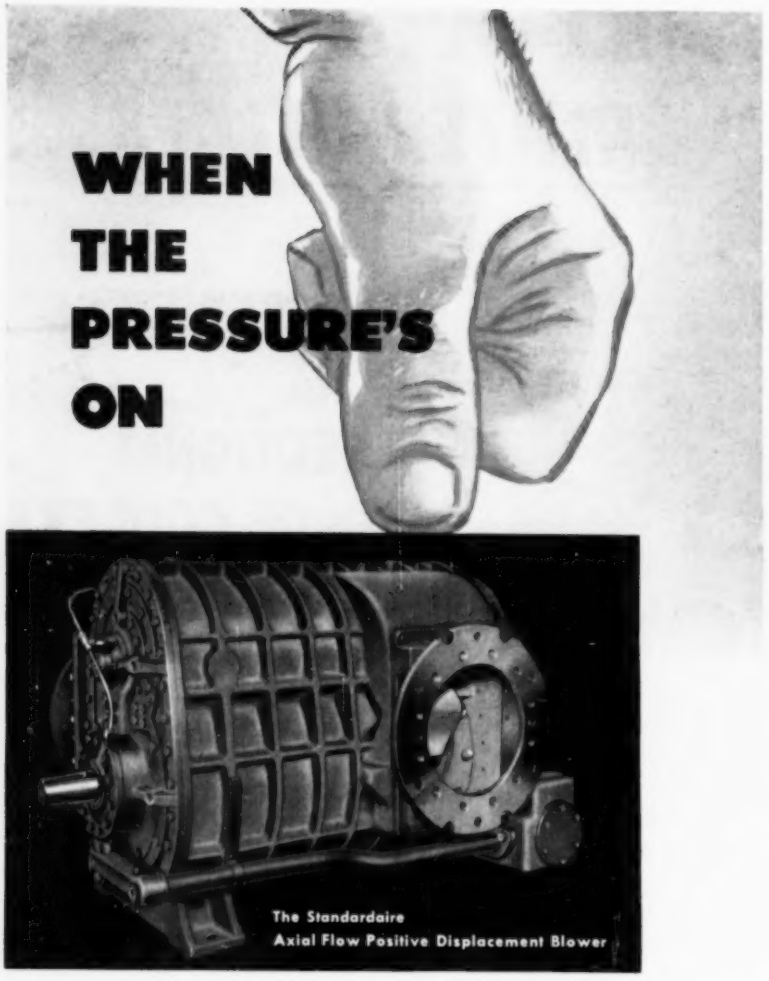

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TORONTO STORY

(Continued from page 18)

Tour No. 3. Frigidaire Products of Canada, Ltd., Scarborough. Limited to 70. Wednesday, April 29.

Just completed plant covering 10 acres utilizing most advanced conveying, assembling and manufacturing procedures to produce electric refrigerators, ranges, etc. A porcelain plant with large automatic pickling machine is of particular interest.

Tour No. 4. Dominion Foundries and Steel Ltd., Hamilton; Ontario Paper Co., Thorold. Tour limited to 75. Wednesday, April 29.

Dofasco is one of Canada's largest basic steel industries manufacturing steel castings, steel plate, tin plate, etc. The Ontario Paper Co. operates a 600-ton a day newsprint mill to supply the Chicago Tribune Co. It sells unbleached sulfite pulp.

Tour No. 5. American Can Co., Hamilton. North American Cyanamid Ltd., Niagara Falls. Limited to 35. Wednesday, April 29.

The Hamilton plant of American Can Co. manufactures a variety of containers. North American Cyanamid Ltd.—major product is calcium cyanamid made by burning limestone in large kilns.

Ladies' Program

Ladies attending the meeting will be specially entertained. Starting Sunday evening April 26 before the Conference opens, motion pictures of unusual interest to both engineers and their wives will be shown. On Monday April 27, while the men attend the afternoon technical session, the ladies will be the guests of the Robert Simpson Co. where they will be taken on a tour of one of Canada's largest department stores and tea will be served in the Arcadian Court.

On Tuesday afternoon, a visit will be made to Toronto's castle, the famed $3,000,000 Casa Loma, where after a tour of its many interesting features, tea again will be served.

Special Speakers

Robert H. Sanders, chairman of the Hydroelectric Power Commission of Toronto will be the Monday luncheon speaker. His address will be an up-to-date report on hydro matters of concern to engineers and executives attending the conference and will deal in particular with the St. Lawrence Waterway Development.

The speaker at the Tuesday luncheon will be C. F. Braun, president of the C. F. Braun Co., Alhambra, Calif., well known for its manufacture of heavy chemical equipment. Mr. Braun's paper "Accounting as a Means of Communication" will wind up what promises to be an outstanding symposium on communications. Other papers will deal with the use of the written and spoken word, semantics and accounting as a means of communication.

The speaker at the Tuesday dinner will be H. L. Keenleyside, director, United Nations technical assistance program.

NEWS

(*Continued from page 27*)

DUST DAMAGE TO COSMOTRON STOPPED

A coating of polyester resin protects the giant cosmotron at Brookhaven National Laboratory, Upton, N. Y., from damage by abrasive particles from the concrete radiation shields that surround it, according to information released by the United States Rubber Co.

The $8,000,000 cosmotron, which is being used in a hunt for basic facts about the atom, is shielded for more than 100 ft. around its circumference by a series of 10-ton concrete blocks stacked four tiers high. The blocks protect personnel from radiation emanating from the cosmotron during operation.

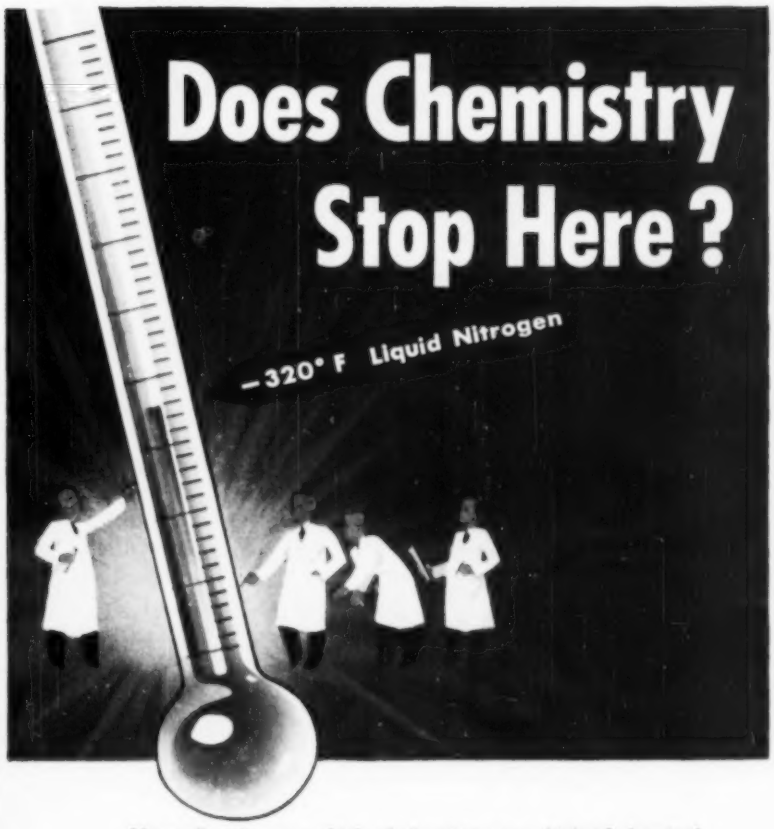
Spray coating concrete radiation shields at Brookhaven National Laboratories with polyester resin.

Because the cosmotron is a delicate piece of machinery, it is necessary to keep the 200-ft. long room virtually dust-free. One of the problems is preventing the concrete shielding blocks, which are occasionally moved, from causing dust. The problem was solved by spraying the blocks with Vibrin, a polyester resin of the Naugatuck chemical division, United States Rubber Co.

DELAWARE RIVER BASIN GETS LIQUID OXYGEN

Liquid oxygen for oxyacetylene processes will be produced by Air Reduction Sales Co., a division of Air Reduction Co., Inc., at a new plant in Riverton, N. J., beginning in 1954. Serving the Delaware River basin primarily, the plant may eventually deliver oxygen to New England and the Carolinas.

(*More News on page 46*)

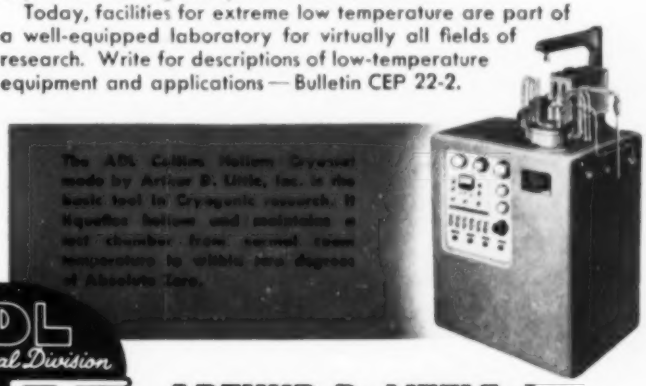


Normally when we think of chemistry, we think of chemical activity at room temperature and above. Yet it is possible that important anomalous behavior will appear in a very small temperature interval . . . perhaps near Absolute Zero.

Although research near absolute zero (−460° F) is relatively new, it is contributing daily to the metallurgists' understanding of the properties of metals . . . And physicists have already discovered promising low-temperature phenomena, such as superconductivity, and are now looking toward their practical application.

At present, low-temperature chemistry is mostly an interesting combination of words. But this is changing. Chemicals which are extremely reactive at ambient temperature may conceivably be stabilized at low temperature. Knowledge of what happens at extreme low temperature can be of particular value to chemists as a key to the explanation of high-temperature reactions.

Today, facilities for extreme low temperature are part of a well-equipped laboratory for virtually all fields of research. Write for descriptions of low-temperature equipment and applications — Bulletin CEP 22-2.



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16 years' use proves PYREX® pipe advantages

Heyden Chemical Corporation, makers of synthetic organics and antibiotics, have used PYREX brand glass pipe since 1937 to eliminate the danger of product contamination, to gain the advantage of visible checks on products in process, and to solve a critical maintenance problem.

The clear visibility PYREX pipe offers is more than a convenience to Heyden. It permits close control and correction of the speed and extent of reactions as they take place, allowing a certainty of results not otherwise attainable.

No product build-up

Heyden's operating experience proves that none of their materials stick to the glass to build up impedance to flow. When cleaning is necessary, it is done simply by flushing the lines with steam.

Plant installation policy requires running PYREX pipe lines out of reach of unskilled workers whenever possible, and instances of breakage have been very rare. Flexible hangers compensate for alignment hazards and the flexibility of the pipe itself allows sufficient deflection to correct what Mr. L. H. Tyler, Department Supervisor, calls the "vagaries of installation."

Mr. Tyler estimates that at least 800 feet of PYREX pipe is in use in the processing areas of the Heyden plant at Fords, N. J. This does not include long outdoor lines between buildings and to loading and disposal facilities, some of which have been in continuous use since 1937.

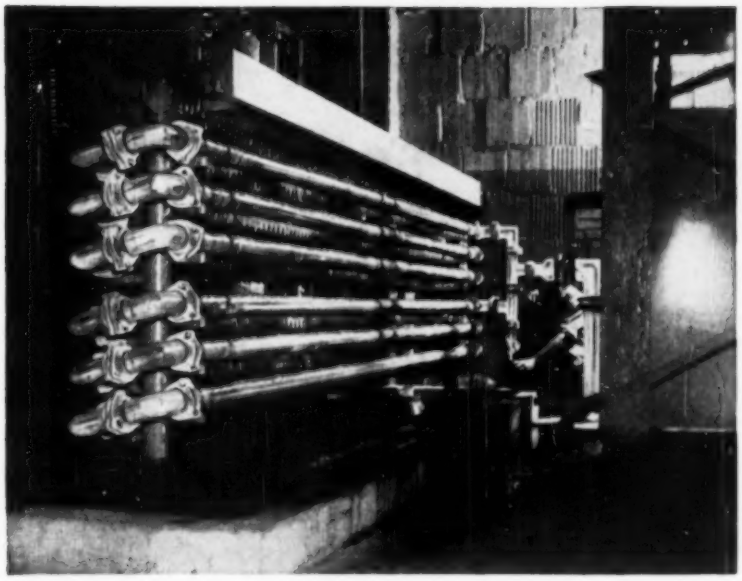
Many applications in plant

There are some two dozen installations in this plant similar to those pictured here, in addition to a number of individual jacketed-pipe condenser units.

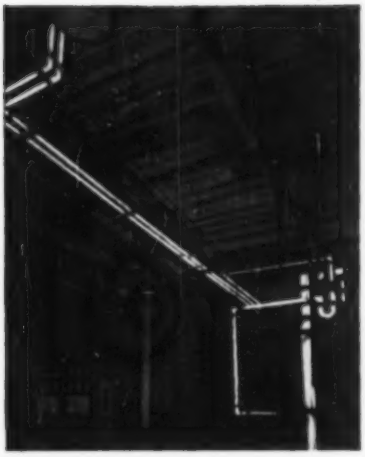
The PYREX pipe distributor nearest you will welcome an opportunity to discuss process fluid handling problems in your plant. He is well informed on the advantages, limitations, and proper installation techniques for PYREX "Double-Tough" glass pipe, and he is backed by the technical experience of Corning engineers. We suggest that you get in touch with him.

Chlorinated aromatics are made in this newest of many reactor and condenser arrangements in Heyden's Fords, N. J. plant. This picture shows one of the reaction kettles in operation. Some of the lines visible above and behind the kettle are 2", 4" and 6" PYREX "Double-Tough" glass pipe which operate at a pressure range of zero to 25 PSI; temperature range: room to 120°C.

in processing fine chemicals



This cascade-type condenser is on the floor above the reactor and condenser installation shown at the left. It consists of twelve lengths of 2" x 12' PYREX "Double-Tough" heat exchanger pipe and is equipped with drip fins. Gaskets are Teflon. (Heyden has developed a "Teflon bellows" connector for joints subjected to unusual vibration, such as at pumps.) The operator is taking a sample from the PYREX header which supplies product to the first and fourth runs.



This shows parts of two phases in the purification of acid-bearing toluene. Along the ceiling beam at the upper left a pair of 1" PYREX pipes lead from outdoor storage tanks to processing equipment on the floor above. The vertical 6" PYREX open column at the right originates in a kettle on the floor below and supplies a condenser slung from the ceiling to the right of the picture. A 2" PYREX trap connects to the condenser exit and from this trap a 2" glass pipe line runs downward under the stairway landing and out to any of a group of outdoor storage tanks or to any of fifteen kettles, depending on requirements.

The PYREX pipe distributors listed below carry the complete line. *Contact the one nearest you:*

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CHICAGO 44, ILLINOIS
Fred S. Hickey, Inc.

NEW ORLEANS, LOUISIANA
W. H. Curtin & Company

CAMBRIDGE 39, MASS.
Macalaster Bicknell Company

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- ☐ "Installation Manual" for PYREX brand "Double-Tough" Glass Pipe (PE-3)
- ☐ "PYREX brand Glass Pipe in the Process Industries" (EA-1)
- ☐ "PYREX brand 'Double-Tough' Glass Pipe and Fittings" (EA-3)
- ☐ "PYREX Cascade Coolers" (PE-8)
- ☐ "Plant Equipment Glassware for Process Industries" (EB-1)

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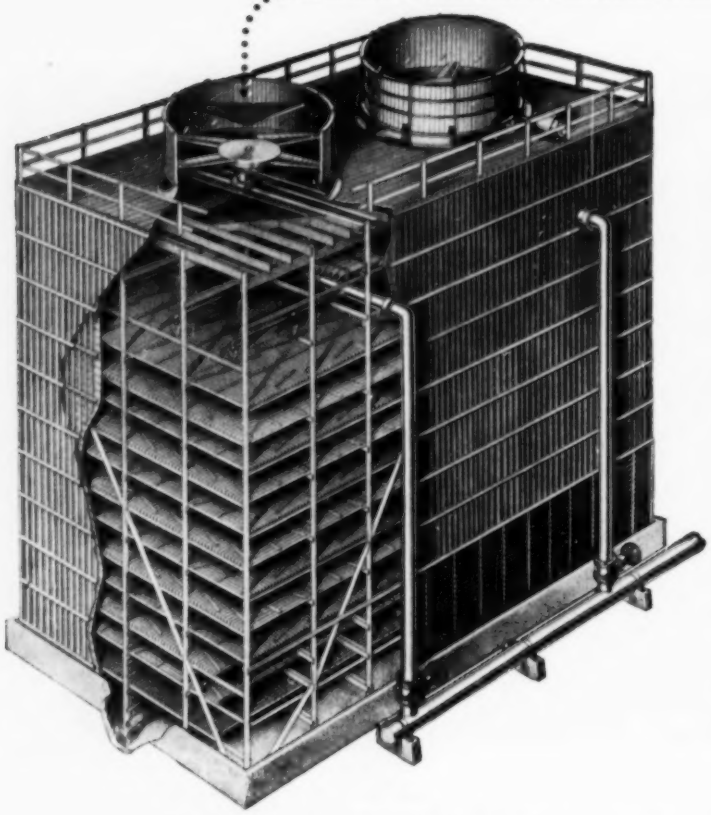

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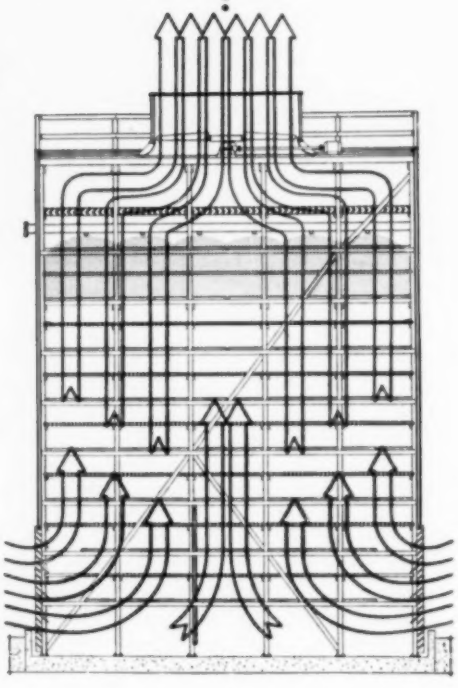
Heavy stainless steel fan blades are finely balanced, resist corrosion and are mounted on shafts whose exceptionally high fatigue strength has been substantiated by strain gauge tests and actual use. Pitch is adjustable to efficiently handle required air volumes at minimum tip speeds and horsepower requirements – more air per kilowatt. Speed reducers incorporating spiral bevel gears feature oil-bath lubrication and dry-air breather. The low-speed fan shaft is mounted on special steep angle thrust with radial bearings to take the combined gear thrust, fan thrust and weight of fan assembly. Driving mechanisms are built for hard-wearing, maintenance-free performance and for smooth, quiet operation.

Vibration Cut-out switches, exclusive with Fluor Cooling Towers, are an emergency safety device that stops the motor should excessive vibration accidentally occur, preventing possible damage to the tower or mechanical equipment. Design employing internal gusset plates duplicates that used in wooden bridge construction. These connectors add greater tensile and compressive strength to structural members, lower the total weight of towers, require less erection time and materially increase tower life. Sloping grid decks of rough-finished redwood with minimum one-inch dimension are used as scaffolding during erection and provide maximum deck surface with negligible air pressure drop through the tower.



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2 • *TEFLON PRODUCTS.* Gaskets, sheets, tubes, packings from Raybestos-Manhattan, Inc. made from Teflon. Varies from white to gray, good resistance to chemicals, heat and moisture. Bulletin.

3 • *DRYERS AND COOKERS.* Standard Steel Corp. bulletin on Hersey cookers and dryers. One-piece, high-strength, steel-agitator arms. Heavy glands and stuffing boxes. Special grease seal.

4 • *GAS METERS.* Booklet on gas meters measuring quantities 4,000 to 1,000,000 cu.ft. from Roots-Connersville Blower Division of Dresser Industries, Inc. Descriptions, illustrations, selection tables, etc.

5 • *SPRAY NOZZLES.* Spray Engineering Co. bulletin covers line of spray nozzles. For use in soap, oil, chemical, dairy industries. Features spray-distribution charts at various pressures for each type.

6 • *WHITING HANDBOOK.* Handbook covering all Whiting Corp. products, including Swenson equipment for chemicals and foods, materials-handling equipment; foundry and transportation equipment, etc.

7 • *PLANT EQUIPMENT.* Posey Iron Works, Inc. folder on various facilities, including steel plate, foundry, heating, and steel form divisions. Illustrated.

8 • *TAPES AND SHEETS.* Teflon tapes and sheets used in various industries covered in bulletin by Continental-Diamond Fibre Co. Included are samples of Teflon, tables of typical property values, thickness ranges, other data.

9 • *FUEL OIL HEATER.* Paracoil type GF gas-fired fuel-oil heater product of Davis Engineering Corp., oil-heated without steam preheating. Permits use of less expensive No. 6 fuel. Diagrams, illustrations, operating data.

10 • *POLYVINYL GASKETING.* Tygon polyvinyl resin, corrosion-resistant gasketing from U. S. Stoneware. Sheets available in two forms. Used in chemical, pulp and paper, petroleum, textile industries. Dimensions, recommendations, etc., in bulletin.

11 • *LABORATORY EQUIPMENT.* From E. H. Sargent & Co., 1,465 page, 1953 catalog on laboratory instruments, apparatus, and chemicals. Available to qualified laboratory personnel, on request.

12 • *EJECTORS.* Jet-Vac Corp. folder on ejectors. Basic specifications, multistaging, interstage condensing pressure, moisture and saturation. Range of pressures, temperature graph, other data.

14 • *POROUS MEDIA.* For filtration and diffusion, Aloxite a porous media by Carborundum Co. described in comprehensive bulletin. Types and uses described.

15 • *"THE LABORATORY."* Published by Fisher Scientific Co. Vol. 22, No.1, deals with latest developments in laboratory instrumentation and technique. Sections on bath systems, flow meters, semimicro centrifuge, etc.

16 • *PAPER BAGS.* International Paper Co. makers of Bagpak multiwall paper bags describe full line. Five basic types. Reinforced cushion stitch closures protect against sifting, moisture, infestation.

17 • *CORROSION-RESISTANCE PRIMER.* Carboline Co. primer for corrosion-resisting synthetic resin protective coatings. Leaflet gives complete test report, colored illustrations of results. Resists dry heat to 350° F.

18 • *TUBES AND FITTINGS.* Steel and stainless steel tubes, stainless and carbon steel welding fittings from Globe Steel Tubes Co. described in bulletin. Used in dairy, meat, sugar, beverage, chemical plants. Typical analyses on various materials, tables of sizes and wall thicknesses, tolerances.

19 • *CHAYEN PROCESS.* Sharples Corp. bulletin describes application

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of Chayen process for continuous cold extraction of fats and oils from cellular material. Applied to degreasing of bone. Explains principle of impulse-rendering. Fat comes out white, bland, solid, high purity. Ready for sale three minutes after bone is fed to impulse renderer.

20 • DEMINERALIZED WATER. "Uses for Demineralized Water," available from research department, Barnstead Still & Sterilizer Co. Comprehensive information on uses, advantages, etc.

22 • SERVO AMPLIFIERS. Industrial Control Co. Servo amplifiers, dc millivoltmeters, analyzers, motor controls. Detailed in loose-leaf folder. Specifications, applications of each product, conversion factors, other data.

23 • WIRE CLOTH. Wire cloth, filter cloth and other fabricated products, catalog of Multi-Metal Wire Cloth Co., Inc. Handbook for engineer-designer of process units. Replete with illustrations, tables, materials of construction, other pertinent data.

24 • AGITATOR DRIVES. Pacific Western vertical agitator drive bulletin now available from Western Gear Works. Driving motor is integral part of unit. Covers single, double, triple agitator units, offers space advantages.

25 • PIPE. Electric resistance weld pipe from Kaiser Steel Corp. Sizes $5^{9}/_{16}$ in. to 14 in. O.D. Roundness and concentricity speed line-up. Coated on request. Hydrostatic pressure quality tested.

26 • ROTARY DISTRIBUTORS. From Ralph B. Carter Co. bulletin on rotary distributors and automatic dosing siphon. Detailed descriptions, illustrations. Principal use is in trickling filtration of sewage or industrial waste.

27 • FLOW METERING. Bulletin from Brown Instruments Division, Minneapolis-Honeywell Regulator Co. covers various phases of fluid flow technology. Flow cost accounting, description of metering systems, meter construction, installation diagrams, electronic integrating.

28 • LIQUID SCALE DATA SHEET. Richardson Scale Co. offers data sheet on automatic, gravity-operated, liquid scale. Capacity, rate of discharge, information on operation, drawings, etc.

29 • CENTRIFUGAL PUMP. General-purpose centrifugal pumps, cradle-mounted, described in Ingersoll-Rand brochure. Five basic types, seventeen corresponding pumps. Section on special purpose units and design modification. V-belt or reduction gear drives.

30 • COTTONSEED OIL. Lukenweld, a division of Lukens Steel Co., announces series of "package plants" for solvent extraction of cottonseed oil. Flow diagram of process in color.

31 • ACID AND CHEMICAL PUMPS. Lawrence Pumps, Inc. centrifugals for pulp and paper, textile and chemical-processing plants. Bulletin gives schematic drawings, table of materials for pumping variety of liquids, etc.

32 • FLOW INDICATORS. For use with liquids, gases, vapors, slurries, sludges, if translucent enough to permit observation. Flow indicated by position of a flapper or ball, or by rotation of wheel observed through sight glass. Schutte and Koerting Co. Tables of operating pressures, temperature, dimensions, and weights.

33 • FLUOROLUBES. Hooker Electrochemical Co. bulletin covers seven grades of Fluorolubes from light oils to waxlike materials. Used as lubricant, sealant. Gives structure, stability, toxicity, viscosity. Sample quantities available for pilot plant.

34 • PROCESS EQUIPMENT. For process engineers, catalog by Patterson Kelley Co., Inc. Featured is twin-shell dry blender but lists also characteristics, applications, capacities for other blenders, kettles, evaporators, pilot-plant units, and heat-exchangers.

35 • FLOOR GRATINGS. Aluminum floor gratings from Borden Metal Products Co. For use in ships, power-

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houses, sewage plants. Require no painting, reduce fire hazards in confined areas. Welded, pressure-locked or riveted-types.

36 • MOTORS. Speed-Trols, variable-speed electric-power drives, 20 to 25 hp. with 2-1 to 4-1, speed variation available in totally enclosed fan-cooled models. Sterling Electric Motors, Inc. System provides for internal and external cooling.

37 • NYLON COUPLING. Inexpensive nylon-gear-type coupling for fractional hp. drives. Construction same as larger units. Available for nominal bores to ⅜ in. diam. from John Waldron Corp. Bulletin.

38 • CRUSHER. Gyratory, jaw, and roll crushers, rotary kilns, dryers and coolers. Bulletin from Traylor Engineering and Manufacturing Co. Exploded views, illustrations, instructions for installation and operation.

39 • FANS. Induced draft bifurcator fans which provide controlled draft for boilers and furnaces. Catalog of DeBothezat Fans Division of American Machine and Metals, Inc. Motor housed in isolated chamber. Twenty-four sizes ranging from a 12-in. to 36-in. fan wheel.

40 • HIGH VACUUM APPARATUS. A 56-page booklet revised to include vacuum connectors, couplings, etc., for industrial use. Complete descriptions of all available items, with tabulated data and illustrations. Central Scientific Co.

41 • CONTROL VALVES. Pneumatic butterfly control valves from Brown Instrument Division of Minneapolis-Honeywell Regulator Co. Designed for regulation of air, gas, liquids. High capacity. Two types, sizes 1½ to 6 in. Wing rotation 68°.

44 • SOLENOID VALVES. Stainless steel solenoid valves for automatic or remote control, emergency shutoff, drum filling. Use with light or viscous distilled or corrosive liquids. Regular and explosion-proof types. Bulletin from R. G. Laurence Co.

45 • LIQUID FILTERS. Removal of rust, dirt, pipe scale, other contaminants from process liquids in a bulletin describing Staynew liquid filters. Dollinger Corp. Partial list of filtering media, illustrated applications, cutaway views, etc.

46 • GLASSED STEEL EQUIPMENT. From The Pfaudler Co. buyers' guide to its equipment and services. Specialize in synthetic detergent, pesticide plants, solvent- and acid-recovery systems, resin and plastic, and others. Filling machines, reactors, heat-exchangers, etc.

EQUIPMENT

50 • AERIAL COOLERS. Drayer-Hanson, Inc. aerial coolers for exhaust steam, lubricating, cutting, transformer and quench oils, also vertical air-flow coolers. Construction details in bulletin.

51 • CHEMICAL MIXER. Homomix chemical mixer without mixing tank from American Well Works. For uniform blending of a liquid with one or more chemicals. Leaflet illustrates application, gives exploded view with dimensions and other data.

52 • POLYETHYLENE PIPE AND TUBING. American Agile Corp. announces pure, unpigmented polyethylene pipe and tubing, Agilene CP, 1 to 2 in. diam. in 20-ft. lengths. Tubing ¼ in. to 30 in. I.D. The ¼- to 1-in. diam. available in coils. Wall thicknesses as required.

53 • FLOW TEST KIT. Portable wide-range flow test kit for laboratory and field checking of liquid or gas flow from Fischer & Porter Co. Predictable at fraction cubic centimeters per minute. Check calibrations eliminated.

54 • RELIEF VALVE. Adjustable, low-pressure relief-type valve for control of gases. Provides protection in systems where leakage cannot be tolerated. Aluminum, brass, stainless. Temperature 40 to 280° F. James-Pond-Clark.

55 • SEWAGE PUMPS. Announced by Deming Co. vertical sewage pumps. For fluids 2- to 4-in. size; for solids handling 1½ to 3 in. diam. Capacities 50 to 1,000 gal./min., heads to 60 ft. Feature thrust bearing assembly. Enclosed impeller, 2-vane, nonclog type. Bulletin.

56 • POWERACTOR POSITIONER. Accurate position of cylinder-operated devices is function of Poweractor positioner by Foxboro Co. Operates from 3 to 15 lb./sq.in. pneumatic controller. Handles to 150 lb./sq. in.g. air supply. Responds to signal pressure change ¼ to 1% range.

57 • GREASELESS STOPCOCK. Laboratory Equipment Corp. assembly of glass and rubber, greaseless stopcock. Controls gas and liquid flow where absence of grease is major factor.

59 • RUBBER HOSE. Republic Rubber Division of Lee Tire & Rubber Corp. producing special flexible, high-pressure industrial rubber hose. Mandril-cured, lengths to 60 ft. Reinforced by textile carcass. Carries gases and fluids under high and low pressures.

60 • WELDED FITTINGS. From Midwest Piping & Supply Co., welded-fittings, corrosive-resistant fittings are stress-relieved. Catalog available.

62 • RIGHT-ANGLE DRIVE. Reeves Pulley Co., fractional hp. vari-speed motor-drive with right-angle reducer. Output shaft drives up, down, or right angle in vertical model.

63 • VACUUM PUMP. For drying blood plasma, metallic salts, high-vacuum evaporation of metals, sealing containers, Microvac pump mod-

el-G from F. J. Stokes Machine Co. Stuffing boxes, valves eliminated.

64 • ***PRESSURE TRANSMITTER.*** Penn Industrial Instrument Corp. bulletin on pressure pneumatic transmitter. Output pressures 3 to 15 or 5 to 25 lb. regardless of range, 6 or 8½ in. sizes. Ranges from vacuum to 10,000 lb./sq.in.g.

65 • ***GAS HEATER.*** Ferrolum lead-clad steel direct-fire gas burner for heating corrosive acid solutions from Knapp Mills, Inc.

66 • ***BUCKET ELEVATOR.*** For loading feeder storage hoppers, Omega Machine Co. bucket elevator. Height, 25 ft., 1½ hp. gearhead motor, delivers 200 cu.ft./hr.

67 • ***FOOD FREEZER.*** Fully automatic continuous-conveying system for rapid freezing of packaged foods from The Girdler Corp. Votator apparatus consists of conveyor and automatic loading and unloading facilities, refrigeration coils and fans. Handles all standard size and shape packages. Prevents formation of large ice crystals.

68 • ***B.t.u. METER.*** From Brown Instruments Division of Minneapolis-Honeywell Regulator Co. data sheet describing operation and application of Brown B.t.u. meter. Records differential temperature and flow, providing direct B.t.u. reading.

69 • ***BLACK LIGHT UNIT.*** Cooper Hewitt Electric Co. black light unit in 3,660Å. Visible light eliminated by Corning filter. For fluorescence analysis, examination of raw and processed materials in processing industries, and research laboratories.

70 • ***VENTURI VALVES.*** Announced by Crane Co., valves operating on unique principle. Disc in valves is a ball. Rides in cage attached to stem by tee-head slotted construction. Provides accurate control with minimum wire-drawing, tight shut-off, straight-through flow with lower pressure drop.

71 • ***ROLL CRUSHER.*** Mikro roll-crusher for precrushing resistant materials from Pulverizing Machinery Co. Automatic friction overload clutch has manual reset affording protection against overload and sudden shock. Wide range of torque capacities.

72 • ***METERING PUMPS.*** Maisch metering pumps for small volumes of liquid. Controls from minute flow rates ranging to 3.6 gal./min. dispense hot or cold viscous or nonviscous liquids. Central Scientific Co.

73 • ***PALMETTO PACKINGS.*** A 20-page catalog Palmetto packings from Greene, Tweed & Co. Includes details of self-lubricating, molded, and sheet packings, also Teflon, a recent addition. Illustrations, packing application chart, etc.

74 • ***AGITATOR.*** TurboTube, a top-entering agitator. Designed to meet need for agitation in rectangular pickling tanks. Sizes ¼ to 25 hp. Parts in wetted area in required materials. Chemineer, Inc.

75 • ***WATER TREATMENT.*** Single pumping, pressure treatment of water announced by Sherwood Water Treatment Co. Heart of system is synchronized Oxidator which oxygenates water with free oxygen. Bulletin.

76 • ***PULP PRESS.*** Intermediate size continuous process Zenith pulp press by Jackson & Church Co. for separation of liquids from solids. Used in paper and viscose pulp, cannery wastes, reclaimed rubber, fruits, etc. Folder.

77 • ***COMPUTER.*** Beckman Instruments, Inc. Computer for solving equations, or as a simulator or tester. Solves up to 7th order, linear total differential equations. Ten-channel operational amplifier and power supply performs summation, sign reversal. Accuracy of 1% per stage.

78 • ***NON-SLIP HANDWHEEL.*** Non-Slip handwheel introduced by Lunkenheimer Co. Features four finger-spaced lugs, continuations of spokes projecting from stem hub through octagonal frame.

79 • ***ELECTRICAL CONDUIT.*** Sealtite flexible electrical conduit new with American Brass Co. Extruded synthetic covering protects wiring against moisture, oil, chemicals, corrosive fumes on installations.

CHEMICALS

85 • ***INDUSTRIAL CHEMICALS.*** Bulletin from Harshaw Chemical Co. covers industrial and laboratory chemicals. Sections on preformed catalysts, process materials, driers, metallic soaps, pigments. Tables of properties.

86-87 • ***SORBITOL.*** *(86)* 24-page digest-size booklet from Atlas Powder Co. explains uses and qualities of sorbitol as used in chemical, food, drug, textile, paint, and other process industries. Tables and charts define composition and properties of sorbitol products. *(87)* "Chemmunique," bimonthly pocket-size publication, presents information on new and old uses of Atlas chemical products and Darco activated carbons. Nontechnical style. Illustrated with color cartoons.

88 • ***COATINGS.*** Flexcoat maintenance coating protects against corrosion by atmospheric conditions, vapors, chemical splash, etc. Can be brushed, sprayed, dipped, applied over old paints. Good adhesion to metal, wood, or concrete. Flexrock Co.

89 • ***COLD BOND SYSTEM.*** For bonding Neoprene sheets to equipment. Gates Engineering Co. Gaco cold bond system. Cured film thicknesses of 1/16 to 3/16 in. in single applications. Any ultimate thickness. Easy repair of damaged areas. Tables of properties of cured sheets.

90 • ***CHLOROACETALDEHYDE.*** Announced by Dow Chemical Co. commercial production of chloroacetaldehyde. Technical booklets on styrene oxide, chloroacetaldehyde and hydraulic brake fluids available. Information on properties, uses, reactions, handling data.

91 • ***KALABOND.*** For bonding GRS, neoprene, and nitrile rubber to iron, steel, monel, magnesium. An 8-page brochure from General Tire & Rubber Co. Contains no halogens. Has anticorrosive properties, is uniform and stable. Summary of adhesion data.

93 • ***ORGANIC CHEMICALS CATALOG.*** Distillation Products Industries, division of Eastman Kodak Co. revised edition (217 pp.) of organic chemicals catalog. Includes new section on notation of organic chemicals. List #38.

94 • ***METHYL AMYL ALCOHOL.*** Technical bulletin on bulk methyl amyl alcohol, from Carbide & Carbon Chemicals Co. Used in protective coatings, and flotation of some nonferrous ores, as raw material for solvents, plasticizers, collector for ore flotation.

Picture of A CONTINUOUS WAY TO PROCESS HOT* CHEMICALS

* Materials With Temperature Up to 1900° F. Are Being Sucessfully Handled. Tests Indicate Possibility Of Handling Even Hotter Materials

Here's a way to engineer efficient, continuous-cooling or conveying into your hot material processing.

Sandvik's steel-belt continuous coolers carry the material on a solid, endless, steel band of flat, stainless or carbon steel. This band "floats" on a patented water-bed arrangement which cools from beneath . . . no water gets on top of the band.

You can cool and convey, regulate thickness and graduate temperature while cooling, obtain desired sizes in the same operation, cool and strip off gelatinous materials in sheet form, cool loose and pulverized materials, cool solids in sheet form or crystallize liquids.

A steel belt provides a smooth, hard, impervious surface that is easy to keep clean. It has a high load capacity and a long service life. It can be fitted with simple discharge devices that scrape material off at any point. It can be of any length or width.

Sandvik steel belt units *without* the patented water-bed cooling arrangement can be used for other chemical processing functions such as drying, evaporating, conveying, carrying material through ovens, etc.

ENGINEERING SERVICE—Sandvik's engineering department will be glad to work with you in designing a conveyor to fit your operation. Sandvik has had over thirty years of experience in designing units to operate either as independent units or as integral parts of special processing equipment.

Write, wire or phone for further information.

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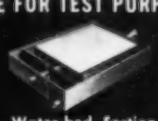
111 Eighth Ave., New York 11, N.Y. WAtkins 9-7180

SS-89

SANDVIK STEEL BELT CONVEYORS

PILOT SCALE UNITS AVAILABLE FOR TEST PURPOSES

Experimental units are available to help you determine cooling rates and other data for your specific material.


Water-bed Section Test Tank

Complete Experimental Water-Bed Belt Cooler

SECRETARY'S REPORT

S. L. TYLER

The actions of the Executive Committee for February were taken by mail ballot because of the impossibility of setting up a definite meeting date and also because of the nature of the prospective actions.

The Minutes of the previous meeting held on Jan. 16 were approved as issued. No adverse comments had been received regarding the applicants for membership whose names were published in the January issue of "C.E.P.," hence all applicants were elected to the grades of membership as indicated.

Student members numbering 188 were elected.

The action accepting the resignation of two members at the January meeting was rescinded as these members have since made required payments.

The Secretary reported that the following four members had been removed from the Suspense List owing to their discharge from the Armed Forces and their return to civilian activities: R. A. Arnold, M. Golden, G. O. Herold, J. B. Moore.

The following five members were placed on the Suspense List because of their having entered the Armed Forces: F. A. Butler, R. G. Garvin, K. D. Raven, P. J. Sievering, S. Stolton.

Upon recommendation of the Student Chapters Committee, J. M. Madigan was appointed counselor of the student chapter at Fenn College to succeed A. J. Teller and M. Smutz was appointed counselor of the student chapter at Iowa State College to succeed G. H. Beyer.

Appointments were made to the Future of the Institute Committee, Industrial Waste Disposal Committee, Professional Guidance Committee and the Program Committee upon the recommendation of the respective chairmen. F. J. Van Antwerpen was appointed Institute representative on the Committee on Atomic Energy of the Engineers Joint Council. W. T. Dixon was appointed one of two delegates to attend the fifty-seventh annual meeting of the American Academy of Political and Social Science to be held on April 10 and 11 in Philadelphia.

1952 Student Contest Problem and Solution

The 1952 Student Contest Problem with the first prize-winning solution of Harold Hublein of Cooper Union is now available through the Secretary's Office for $1.00.

BOOKLET DESIGNED FOR CHEMISTRY ASSISTANTS

"Handbook for Chemistry Assistants" is the title of a 32-page booklet, prepared and published by the Handbook Committee of the General Chemistry Workshop of the Committee on Teaching of College Chemistry, Division of Chemical Education, American Chemical Society. For young, inexperienced teachers easy-to-read chapters on conducting a recitation period; conducting a laboratory period; safety measures; first aid procedure, etc., are attempts to answer a long-felt need in the education world where a large share of chemistry instruction is borne by graduate and undergraduate student assistants.

Copies are available without cost from Educational Service department, Fisher Scientific Co., 717 Forbes Street, Pittsburgh 19, Pa., through whose facilities the book was published.

A New High in Metering Efficiency

MAISCH

Stainless Steel Metering Pumps

- Variable Capacities—0 to 3.2 gal./min.
- Fixed capacity units .175 to 4.8 gal./min.
- Sterilizable by steam autoclaving.
- Made of non-pyrogenic materials.
- Pump instantly detachable.
- Easily disassembled for cleaning.
- Non-pulsating positive displacement.
- Self-lubricating oilless bearings.
- Automatic volumetric dispensing controls available.

These pumps are designed and built for those requiring the utmost in accuracy and dependability in the metering of small volumes of liquid. They provide for precision control in the dispensing of hot or cold viscous or non-viscous liquids such as soaps, oils, perfume, liquid fat, wax, glue, beverages, fruit juices and numerous chemicals. And they have been found equally valuable for the control of biological fluids and other sterile solutions.

The flow of the Maisch Pump is continuous, smooth and non-pulsating. Variable speed is instantly adjustable to the exact amount desired from zero/ml sec to the maximum capacity of the pump. The simple design permits easy disassembly for cleaning and sterilizing.

Materials used in Maisch Pumps are non-pyrogenic and remain sterile while dispensing sterile liquids. They resist corrosion and chemical reaction of most liquids and do not contaminate or otherwise affect the quality and flavor of beverages.

Maisch Pumps are available in a wide variety of types and capacities ranging from zero to 4.8 gallons per minute.

Ask for Bulletin No. CNC 76.

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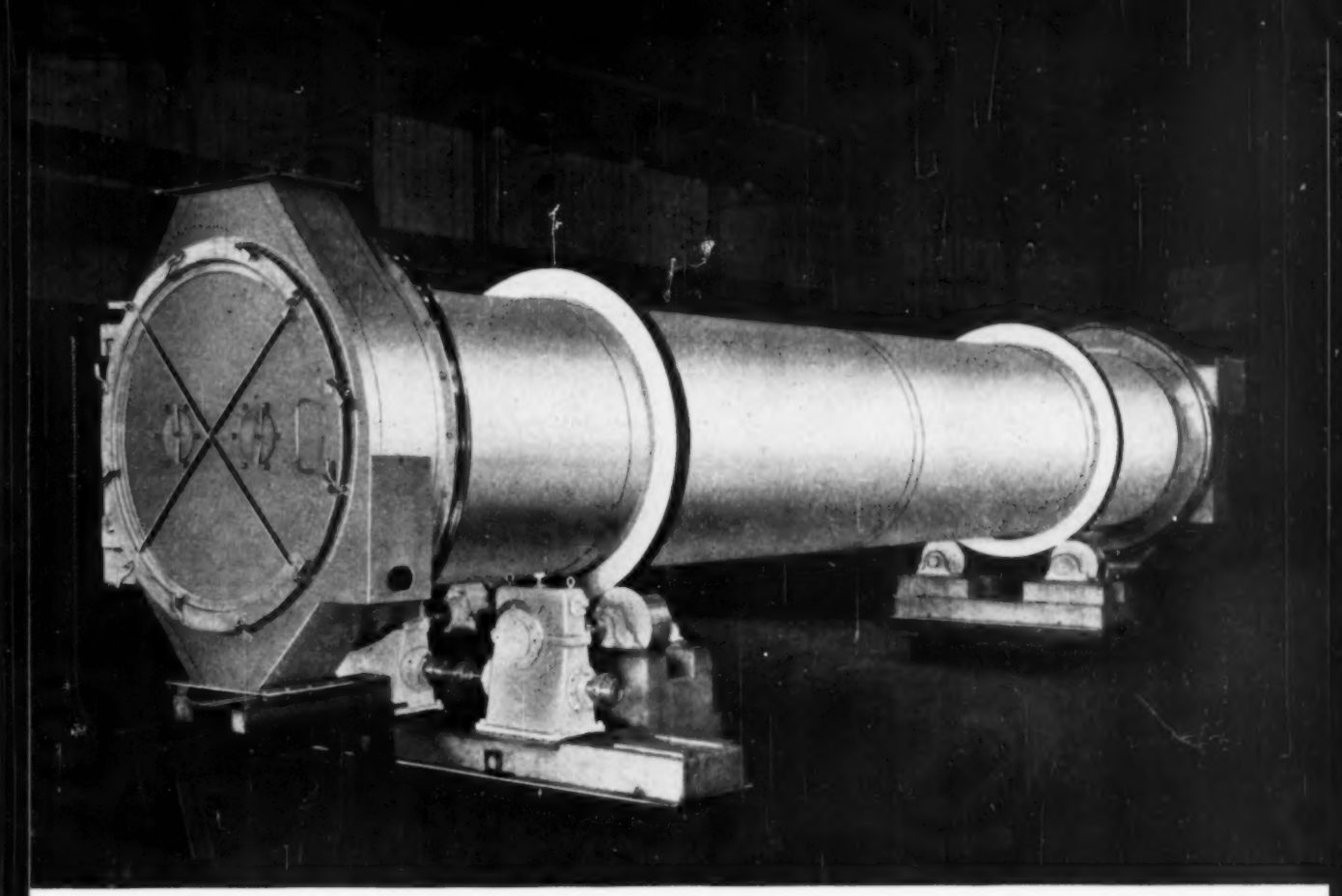
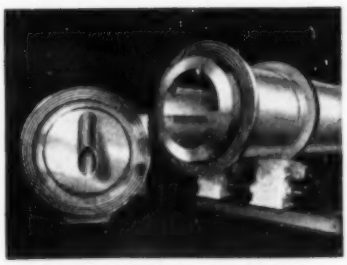
. . . one dependable source of supply for everything you need in scientific instruments and laboratory supplies. Over 15,000 items . . . 14 branch offices and warehouses.

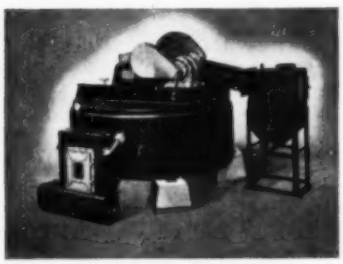


stainless steel Plastics Dryer

prevents product contamination



Labyrinth Seal on 60" x 32' 0" Stainless Steel Plastics Dryer showing the Mirror-like Finish on the Shell and Flights.



Special Steam Jacketed Batch Dryer showing Dustless Discharge to Screw Conveyor and Condenser where Fines are Reclaimed from Vapors.

● Fabricated entirely of stainless steel, the 60" x 32' 0" dryer pictured above, is probably one of the most costly direct heat rotary dryers ever built. The entire interior, including the flights, is polished to a mirror-like finish, and is easily accessible for cleaning. Feed and discharge breechings and inspection doors are also of stainless steel polished on the inside. Air used in drying is filtered and the discharged air is passed through a special high efficiency dust collector, of stainless steel construction. Fabricated in our extensive machine and structural shops this dryer, built to prevent contamination and spoilage between different batches—and colors—of a well known plastic, reflects the ability of Bartlett-Snow to meet fully the requirements of even the most exacting heat engineering problems.

DESIGNERS
ENGINEERS

BARTLETT-SNOW
CLEVELAND 5, OHIO

FABRICATORS
ERECTORS

Dryers • Coolers • Calciners • Kilns

"Builders of Equipment for People You Know"

Low Cost Protection
for

HEAT EXCHANGER TUBE ENDS

In the past 31 years Conseco has provided millions of Flowrites for tube inlets of heat exchangers operating in all industries and all applications. Tube inlets become eroded and worn long before the remainder of the tube, and by reinforcing the inlets it is possible to increase the effective tube life many times.

Flowrites—made of the same metal as the tubes—are available in any length, diameter or gauge. They are easy to install and remove by unskilled help. When Flowrites themselves become worn (*instead* of the tubes!), just pull them out and install new, longer Flowrites.

Get the facts from the 8-page Flowrite "proof" booklet, available upon request.

CONDENSER SERVICE & ENGINEERING CO.

80 RIVER ST., HOBOKEN, N. J.

SPRAY
NOZZLES
for chemical spraying, cooling, humidifying, dehydrating, and hundreds of other applications
You'll get the *right* nozzles quicker by calling Binks...manufacturers of one of the most complete selections ever produced. A wide range of spray patterns, sizes, capacities... with nozzles cast or machined from standard or special corrosion-resistant metals.
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Binks
A COMPLETE LINE OF INDUSTRIAL SPRAY NOZZLES AND COOLING TOWERS

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before April 15, 1953, at the Office of the Secretary, A.I.Ch.E., 120 East 41st, New York 17.

Applicants for Active Membership

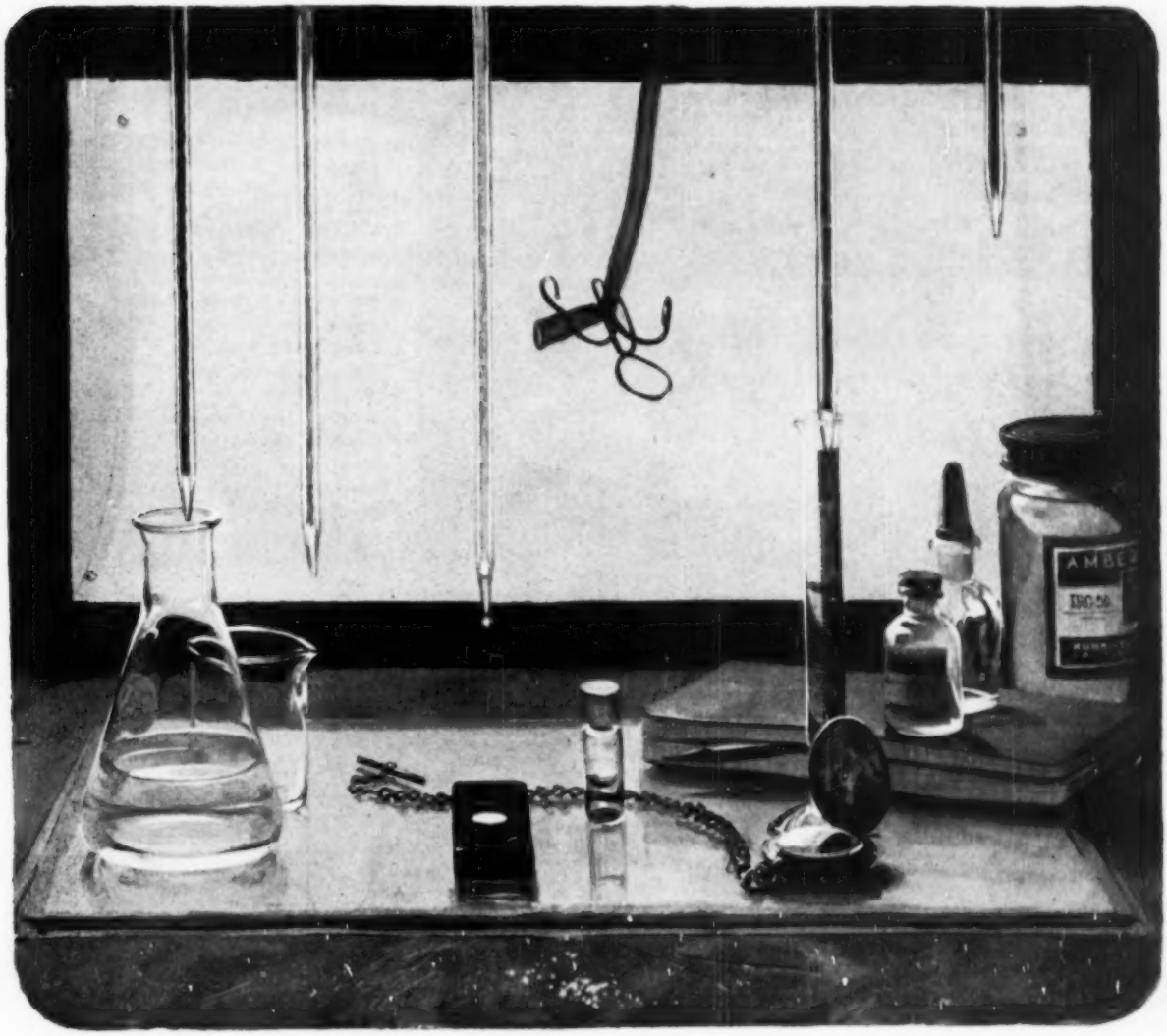
Ackerman, William A., *Media, Pa.*
Atkins, G. T., *Highlands, Tex.*
Blasco, P. A., *Detroit, Mich.*
Buckley, Robert A., *Wilmington, Del.*
Byrne, Thomas J., *El Dorado, Ark.*
Carkeek, Charles R., *Pasadena, Calif.*
Carre, Walter W., Jr., *Pelham Manor, N. Y.*
Carter, Charles E., *Pittsburgh, Pa.*
Carter, Charles H., Jr., *Wilmington, Del.*
Charlton, H. E., *Cheshire, England*
Cooper, Robert H., *Charles City, Iowa*
Cuthbert, C. H., *Petersburg, Va.*
Day, Tom R., Jr., *Painesville, Ohio*
DeHart, H. G., *Irvington, N. J.*
Draeger, A. G., Jr., *St. Albans, W. Va.*
Duckworth, William C., *Atlanta, Ga.*
Eickhoff, Harold H., *Philadelphia, Pa.*
Ferguson, Charles C., *San Francisco, Calif.*
Ferguson, John T., *Edgewood, Md.*
Filbert, Robert B., Jr., *Columbus, Ohio*
Flewellen, E. H., Jr., *White Plains, N. Y.*
Flynn, John V., *Penns Grove, N. J.*
Francisco, Cecil J., Jr., *Homewood, Ill.*
Fredrickson, Russell H., *St. Paul, Minn.*
Friedlaender, William V., *Homewood, Ill.*
Gill, Richard H., *Elyria, Ohio*
Halik, Raymond R., *Pitman, N. J.*
Haney, Stanley C., *Harvey, Ill.*
Harris, Harold R., *Phillips, Tex.*
Hemminger, Charles E., *Westfield, N. J.*
Hoglund, Earl B., *Wilmington, Del.*
Hopkins, John M., *Rodeo, Calif.*
Johnston, Rodney W., *Marcus Hook, Pa.*
Kapp, N. Martin, *Swarthmore, Pa.*
Kemmer, Robert A., *Charleston, W. Va.*
Landau, Frederick W., Jr., *West Point, Pa.*
Lang, William C., *Akron, Ohio*
Lee, Robert E., *Harmony, Pa.*
Lueth, Paul F., Jr., *Rodeo, Calif.*
Magruder, Lloyd B., Jr., *Wilmington, Del.*
Mattioli, Arthur R., *Boston, Mass.*
McCullough, J. H., *Cheltenham, Pa.*
McCune, Leroy K., *Wilmington, Del.*
Miller, Irvin E., *Kansas City, Mo.*
Mitchell, George R., Jr., *Pine Orchard, Conn.*
Mobley, William N., *Richland, Wash.*
Mullen, T. E., *South Charleston, W. Va.*
Orr, Franklin M., *Baytown, Tex.*
Pahl, W. H., *Western Springs, Ill.*
Roberts, Richard R., *Springfield, Mass.*
Rothfus, Robert R., *Pittsburgh, Pa.*
Rylander, Clanton, Jr., *Houston, Tex.*
Stepanek, Joseph E., *Denver, Colo.*
Stevens, Dean, *Cody, Wyo.*
Stringer, J. T., *Richland, Wash.*
Wagenknight, Frank W., *Aldan, Clifton Heights, Pa.*
Underwood, J. E., Jr., *Syracuse, N. Y.*
Walton, Donald R., *Richmond, Va.*
Wells, Frank L., *Rochester, N. Y.*
Wenger, M. E., *Philadelphia, Pa.*
White, G. Edwin, *New York, N. Y.*
White, Gerald A., *Los Angeles, Calif.*
Wickham, Henry P., *New York, N. Y.*
Williams, John S., *Port Hueneme, Calif.*
Young, Thomas R., *Riverside, Conn.*

Applicants for Associate Membership

Alexander, Earl L., Jr., *Wilmington, Del.*
Baum, Alfred G., *Mt. Vernon, N. Y.*
Holmes, Elza O., *Hickman Mills, Mo.*
Janes, W. J., Jr., *Milwaukee, Wis.*
Koehler, John W., *Los Angeles, Calif.*

(Continued on page 44)

METHOD FOR OBTAINING HEALTHY YIELDS



Discovery alone will not bring the benefits of a wonder drug to the waiting world. Ways must be found to manufacture it in quantity at low cost. In the case of streptomycin, the method was provided by AMBERLITE® IRC-50, a Rohm & Haas cation exchange resin.

When standard techniques for extracting antibiotics from fermentation broths proved inefficient, the producers turned to Rohm & Haas Company. Working with the columns shown here, Rohm & Haas chemists learned that a standard, strongly acidic AMBERLITE exchanger adsorbed streptomycin, but with an affinity too great for satisfactory elution. So they synthesized a new, weakly acidic exchanger—and the method became practical. Today this resin, AMBERLITE IRC-50, is used in producing most of the world's streptomycin, by a greatly simplified, lower cost process.

This type of cooperation can be applied to your problem. It may well lead you to a new process, or a better process, through AMBERLITE ion exchange.

AMBER-HI-LITES, *a bi-monthly report on ion exchange, is available on request.*

ROHM & HAAS COMPANY

THE RESINOUS PRODUCTS DIVISION PHILADELPHIA 5, PENNSYLVANIA

The Story of a Test

DURALOY

Test Rod.....12% Cr; CA-14
Test Temperature.....1200°F.
Tensile Strength.....38,200 psi.
Elongation (2")..... 29.5%
Reduction in Area..... 86.1%

That's high quality metal! Metal destined for a high alloy casting which has to meet some pretty rigid specifications!

The story we want to tell here is about our Testing Facilities. We have right in our foundry every conceivable testing facility needed when checking static or centrifugal high alloy castings for industry. Where required, we make complete chemical, metallurgical, and mechanical checks and tests. And have both a 400,000 volt X-ray unit and gamma-ray unit, for checking the final casting for hidden flaws.

As we see it, the only way to assure customers of high quality castings is to have and use all necessary facilities for testing and checking the heat, pour and finished casting.

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Office and Plant: Scottdale, Pa. - Eastern Office: 12 East 41st Street, New York 17, N.Y.

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Atlanta: J. M. TULL Metal & Supply Co. Chicago: P. O. NELSON 332 S. Michigan Avenue San Francisco: JOHN D. FENSTERMACHER 1241 Taylor Street

METAL GOODS CORP. Dallas • Denver • Houston • Kansas City • New Orleans • St. Louis • Tulsa

CANDIDATES

(Continued from page 42)

Raphael, Thomas, *Winchester, Mass.*
Shelton, Fredric, J., *Kent, Wash.*

Applicants for Junior Membership

Armstrong, Glenn K., *Cambridge, Mass.*
Arnold, Robert F., *Texas City, Tex.*
Barker, John E., *Middletown, Ohio*
Bees, John H., *Institute, W. Va.*
Belcolore, Clorindo A., *E. St. Louis, Ill.*
Berner, Robert G., *New Providence, N. J.*
Bobsein, William P., *Norwich, Conn.*
Bunt, Wallace R., *Midland, Mich.*
Carlson, Linus E., *St. Albans, W. Va.*
Cohen, Robert, *Bronx, N. Y.*
Cook, Alfred A., *St. Louis, Mo.*
Corrigan, Arthur Paul, *Ponca City, Okla.*
Crosswait, Mark L., *Louisville, Ky.*
Darby, Bill Joe, *Texas City, Tex.*
Doan, Parker L., *Texas City, Tex.*
Doberstein, Stephen C., *Wilmington, Del.*
Doonan, David F., *Army Chemical Center, Md.*
Erdmann, Donald A., *Neenah, Wis.*
Fairbanks, Daniel F., *Cambridge, Mass.*
Fields, Billie J., *Cleveland, Tenn.*
Fox, Holstein D., Jr., *Cleveland, Ohio*
Frey, Robert J., *Army Chemical Center, Md.*
Galloway, John R., *Akron, Ohio*
Garrett, Robert Y., *Akron, Ohio*
Gottschlich, Chad F., *Cleveland, Ohio*
Greenberg, N., *Philadelphia, Pa.*
Griesmer, Gerard J., *Tonawanda, N. Y.*
Hann, G. Charles, *St. Paul, Minn.*
Harp, Emile F., *Claymont, Del.*
Heidsman, Harry W., *Wilmington, Del.*
Helfand, William H., *Philadelphia, Pa.*
Henriques, Harry P., *N. Plainfield, N. J.*
Herrin, Gareld R., *Ho-Ho-Kus, N. J.*
Hill, Frank B., *Princeton, N. J.*
Hochgraf, Norman N., *Newark, Del.*
Jacoby, John H., *Freeport, Tex.*
Jagel, Kenneth I., Jr., *Hollis, N. Y.*
Jesernig, William John, *Akron, Ohio*
Kapadia, G. S., *Chicago, Ill.*
Kelly, James H., *Tulsa, Okla.*
Kleinman, George, *Chicago, Ill.*
LaCroix, K. D. R., *Baton Rouge, La.*
Langner, Herbert J., *Cicero, Ill.*
Lemieux, Laurent E., *Shawinigan Falls, Que.*
Leslie, J. D., *Detroit, Mich.*
Mark, Lindal, L., *Brooklyn, N. Y.*
McDonnell, Robert W., *Portsmouth, Va.*
McNamee, Richard J., *Oak Ridge, Tenn.*
Mendelsohn, Morris Aaron, *Houston, Tex.*
Menuet, Richard A., *Kansas City, Mo.*
Michelman, Philip, *New Haven, Conn.*
Miller, Sidney G., *El Segundo, Calif.*
Moore, Edward P., Jr., *Wilmington, Del.*
Nabor, George Wm., *Dallas, Tex.*
Newsom, Thomas M., *Baytown, Tex.*
O'Hare, Richard A., *Emeryville, Calif.*
Oxenreiter, Maurice F., *Hammond, Ind.*
Patsavas, Alexander C., *Berwyn, Ill.*
Peak, John C., *Albuquerque, N. M.*
Peters, Robert M., *Cincinnati, Ohio*
Peterson, Theodore I., *Brooklyn, N. Y.*

(Continued on page 46)

Electrolytic Aids to INSECTICIDE MANUFACTURE

Chlorine and caustic soda, products of the electrolytic industry, are essential to insecticide manufacture.

Uniformly high quality **GLC Graphite Anodes** are equally important to the chlorine and caustic soda production of many leading electrochemical manufacturers. The performance of **GLC Graphite Anodes** in electrolytic cell operations is unsurpassed.

ELECTRODE DIVISION

Great Lakes Carbon Corporation

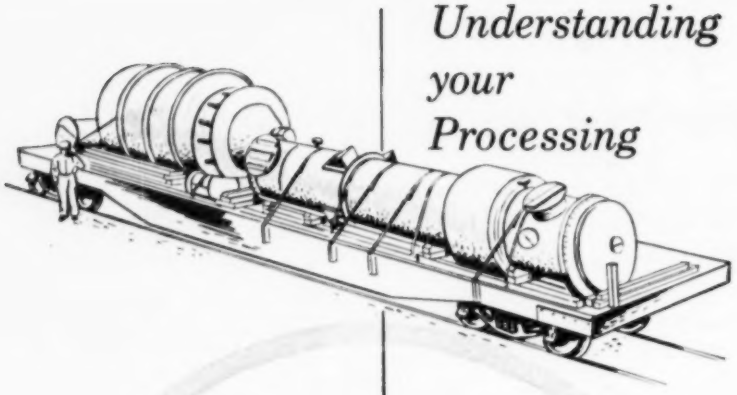
Niagara Falls, N. Y. GLC Morganton, N. C.

Courtesy Piper Aircraft Corporation

Graphite Anodes, Electrodes and Specialties

Sales office: Niagara Falls, N. Y. **Other offices:** New York, N. Y., Chicago, Ill., Pittsburgh, Pa.

Sales Agents: J. B. Hayes, Birmingham, Ala., George O'Hara, Long Beach, Cal., Great Northern Carbon & Chemical Co. Ltd., Montreal, Canada



Understanding your Processing

...we start with that

Yes, we start with a full understanding of your processing requirements. This understanding is supplemented by our experiences in mechanical and process design which enables us to provide the best equipment for your particular problem. Our engineers certainly know processing, and knowing it can appreciate what the equipment is expected to do.

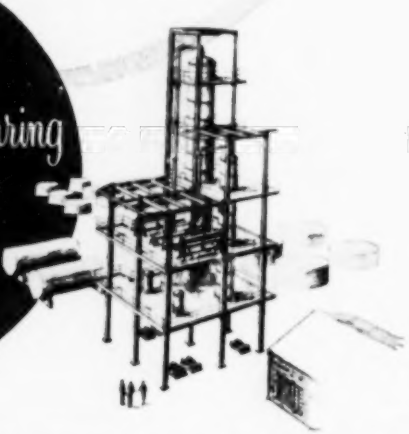
Included in a long and varied list is equipment such as—

Process Units	**Special Coils**
Distillation Columns	**Extraction Equipment**
Pressure Vessels	**Heat Exchange Units**

Our shop men are skilled in fabricating all kinds of materials to close tolerances. They, too, have many years of experience back of them. With this two-fold service available—experience design engineers and skilled shop craftsmen, wouldn't you like to have us work on your equipment problems?

Engineering and Manufacturing

Process Equipment of Our Design to Solve Your Problem



BADGER MANUFACTURING COMPANY

230 BENT STREET, CAMBRIDGE 41, MASS. • 60 EAST 42nd STREET, NEW YORK 17, N. Y.

CANDIDATES

(Continued from page 44)

Potts, Phillip E., *Bartlesville, Okla.*
Quinlan, William J., *Stamford, Conn.*
Rhoads, Darwin E., *Seaford, Del.*
Rickert, Donald L., *Niagara Falls, N. Y.*
Roemelt, Willard F., *Waltham, Mass.*
Ross, James F., *Baton Rouge, La.*
Rozycki, Joseph, *Toronto, Ont., Can.*
Scott, John W., *Louisville, Ky.*
Seay, J. Glenn, *Kansas City, Mo.*
Sherry, Edward V., Jr., *Brooklyn, N. Y.*
Simon, Robert J., *Brentwood, Mo.*
Skaar, Irving William, *Beaumont, Tex.*
Smith, Donald W., *Wilmington, Del.*
Smith, Sidney V., *Houston, Tex.*
Smith, Tyrus R., *Army Chemical Center, Md.*
Stadig, John E., *So. Pasadena, Calif.*
Stern, Robert Leon, *New York, N. Y.*
Swaim, Fred M., *Dumas, Tex.*
Swandby, Earl R., *Waynesboro, Va.*
Sweeney, George C., Jr., *West Newton, Mass.*
Thomas, George N., *Midland, Mich.*
Thompson, George E., *Akron, Ohio*
Ward, John M., *Chester, Pa.*
Weiner, Howard, *Hampton, Va.*
Whitmire, Paul T., *Barberton, Ohio*
Woodmencey, William T., *Bloomfield, N. J.*
Wright, James H., *Pittsburgh, Pa.*
Wright, Paul B., *St. Louis, Mo.*
Young, Grayson S., *Baton Rouge, La.*
Young, James M., III, *Pittsburgh, Pa.*
Zapf, John, *LeRoy, N. Y.*

STUDENTS FROM FRANCE AT UNIV. OF MINNESOTA

Five graduate students from France are enrolled in chemical engineering department at the University of Minnesota, Minneapolis, this year under the directorship of Dr. Edgar L. Piret, professor of chemical engineering. They are: Olegh Bilous, a graduate of École Polytechnique, Paris, who is doing his second year's advanced work, Rolard Boulanger and Jean Van Royen, graduates of the Sorbonne and the École Nationale Supérieure de Chimie, Université de Paris, respectively, together with George Gau and Michel Rouzet from the École Nationale Supérieure des Industries Chimiques, Université de Nancy. These students, who have excellent records and who are already well trained in mathematics, chemistry and physics, are concentrating on the principles of chemical engineering.

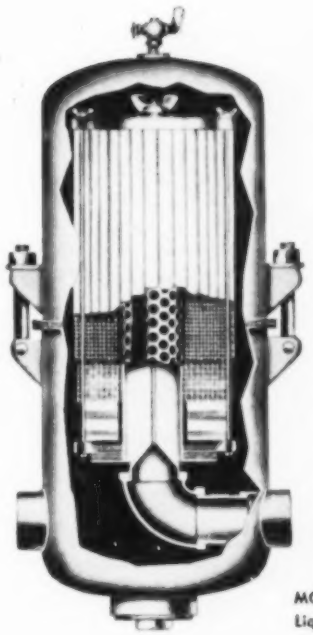
Dr. Piret's interest in this exchange program was an outgrowth of his own experience as a Fulbright research professor in 1951 at the Universities of Nancy and Paris. He discussed his reaction to the profession as it exists in America, and on the Continent in "C.E.P." March, 1952, page 29.

(More News on page 48)

STAYNEW LIQUID FILTERS

PROVIDE DEPENDABLE DAY IN DAY OUT PERFORMANCE

PRACTICALLY any liquid can be efficiently and economically filtered by a Staynew Liquid Filter. They are designed for adaptation to virtually any space requirement or any arrangement of inlet and outlet connections. All known types of filtering media are available to provide any degree of efficiency for any specific problem, or for use regardless of temperature, pressure or corrosion requirement. All units can be constructed according to the API-ASME and the various ASME Code specifications. Staynew Model ELS liquid filters are available in many types of materials other than regular steel, such as stainless steel, monel, herculoy and other non-corrosive materials.



MODEL ELS
Liquid Filter

PARTIAL LIST OF LIQUIDS THAT CAN BE FILTERED BY STAYNEW LIQUID FILTERS

Acetone
Acids
Adhesives
Alcohols
Alkalis
Ammonia
Asphalt
Benzene
Benzine
Beverages
Butane
Casein
Castor Oil
Caustic
Cellulose Solutions
Chlorine
Chocolate
Cleaning Fluids
Coating
Coolants
Cutting Oils
Emulsions
Enamels
Ethanolamine
Ethylamine
Extracts
Flameproofing Solutions
Fuel Oil
Furniture Polish
Gasoline
Glue
Greases
Gums
Hydraulic Fluids
Ink
Kerosene
Lacquers
Latex
Liquid Paraffin
Lubricants
Molasses
Naphtha
Paint
Pharmaceuticals
Propylene
Quenching Oils
Resins
Rubber Cements
Sizing
Soap
Solvents
Steam Condensate
Syrups
Tar
Turpentine
Varnish
Vegetable Oils
Viscose
Water
Wax

SEND for this 12-page bulletin D-IL containing specifications, engineering and performance data, photos and descriptions of recommended types of filter media, check list of liquids that can be filtered and other helpful data.

DOLLINGER Recommended STAYNEW FILTERS

Representatives in Principal Cities

DOLLINGER CORPORATION

79 Centre Pk., Rochester 3, N. Y.

ALL TYPES OF FILTERS FOR EVERY INDUSTRIAL NEED

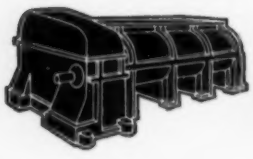
BAKER PERKINS mixers will thoroughly mix and knead almost any material for the chemical processing industry

There is a BAKER PERKINS Mixer built to efficiently mix and knead materials ranging in consistency from dry powders and light fluids to stiff plastic masses. Close clearance between the blades and trough keeps every particle of the material in constant motion so that no part of the batch escapes the thorough mixing action of the blades. Intensive kneading is maintained as the material is pulled and squeezed against the blades, saddle and sidewalls. Consult a B-P sales engineer for full facts.

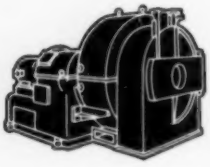
Size 16, NEM B-P "Universal" Mixing and Kneading Machine for heavy plastic masses. Working capacity 150 gallons; total capacity 225 gallons. Fabricated steel trough shell jacketed for 150 psi. steam or water pressure. Cast iron trough ends are not jacketed. Saddle section has thermocouple for temperature control. Cast steel Sigma or Double Naben blades cored for circulating steam or water. Oil tight gear guards; anti-friction bearings. 50 HP motor.

242-A

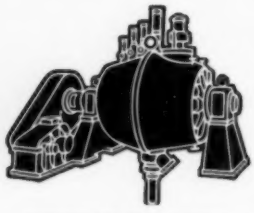
Other BAKER PERKINS products



EQUIPMENT FOR FOUNDRY INDUSTRY



CENTRIFUGALS



EQUIPMENT FOR RAYON PRODUCTION

BAKER PERKINS INC.

CHEMICAL MACHINERY DIVISION • SAGINAW, MICHIGAN

NEWS

(*Continued from page 46*)

COURSES IN PHASE EQUILIBRIA AND AUTOMATIC CONTROL

An intensive two-week summer course in phase behavior of hydrocarbons designed for young engineers in industry and others who may wish an up-to-date refresher course will be given at the University of Michigan from June 16 to 30, 1953.

Four areas of concentration are planned, namely, (1) phase rule and its application to hydrocarbon systems, by Prof. L. O. Case, (2) the separation of azeotropic mixtures, the underlying principles of nonideal solutions and calculations made for designing fractionating systems, by Prof. R. R. White, (3) low-temperature processing, a review of the data available and applications to the separation of liquids from natural gases at low temperatures, by Prof. Brymer Williams, and (4) phase behavior in petroleum reservoirs, a study of techniques and data available for treating reservoir systems at high pressures, by Prof. Donald L. Katz. The fee for the course is $125.

Immediately following the intensive course a two-day research conference will be held, on July 1 and 2, to exchange ideas on laboratory procedures, discuss correlations or data, and generally review the status of current knowledge and needs. One day will be given to papers on recent researches in the field, preprints of which will be available. Attendance at the conference is open to all who are interested in the topic.

The University of Michigan has also announced two intensive courses in automatic control. The first is scheduled for June 15 to 20, 1953, inclusive, and the second for June 22 to 25, 1953, inclusive. The courses, intended for engineers who desire a basic understanding of the field but who cannot spare more than a few days, are aimed at making automatic control easy to learn.

Course I will consist of the fundamentals of measurement, communication, and control and will include some work in nonlinear systems. Course II will consider applications of these fundamentals to advanced problems. There will be four hours of lecture each morning and three hours of demonstration in the afternoon.

Further information on the phase-equilibria course may be obtained from Prof. Donald L. Katz, Room 2028, and on the automatic-control course from Prof. M. H. Nichols, Room 1523, East Engineering Building, Ann Arbor, Mich. April 15, 1953, is the closing date for registration.

(*More News on page 50*)

Chapman Casts World's Largest Stainless Gate Valve

9-ton casting produced in austenitic chromium-nickel stainless steel

This valve, produced by The Chapman Valve Manufacturing Co., Indian Orchard, Mass., for the defense effort, is used in corrosive water service. It is stated to be the world's largest, with an overall height of 19 feet, weighing approximately 18,000 pounds. The rough casting weight was approximately 36,000 pounds.

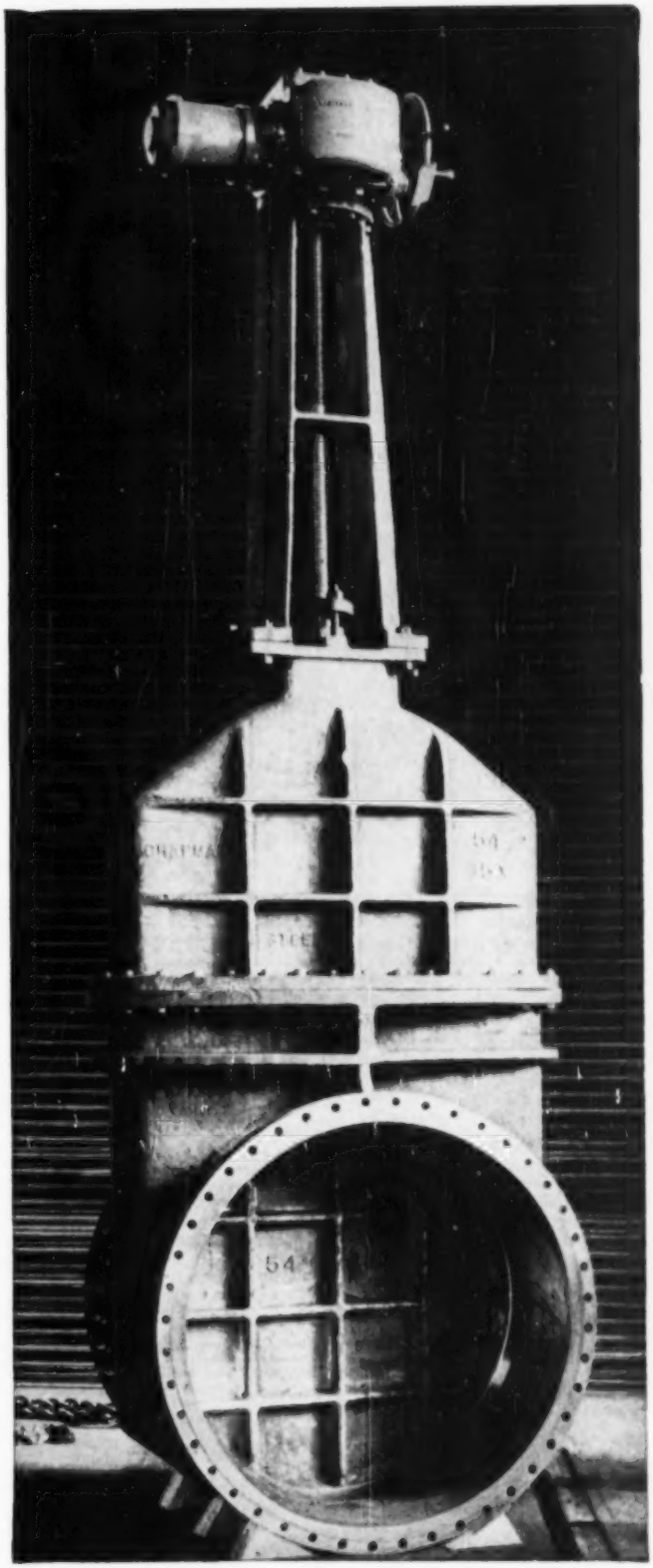
Cast in low carbon 18-8 chromium-nickel stainless steel, it is one more demonstration that size is no limiting factor when you cast parts in stainless steels to provide resistance to corrosion and erosion.

Stainless steel resists attack by nearly all oxidizing acid conditions. In addition, it helps you trim bulk and deadweight without sacrificing strength and safety.

At elevated temperatures, austenitic chromium-nickel stainless steels are distinguished by their strength and outstanding resistance to oxidation. At temperatures down to −320° F. they retain their toughness and unusual strength.

Investigate all the benefits stainless steels can give you. Leading stainless steel companies and foundries produce nickel-containing stainless steels in all commercial forms. A list of sources of supply will be furnished on request.

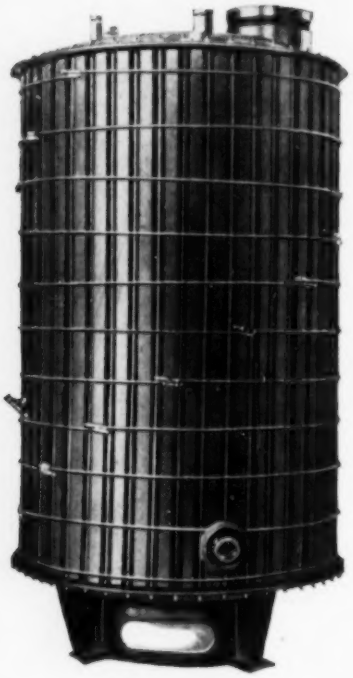
At the present time, the bulk of the nickel produced is being diverted to defense. Through application to the appropriate authorities, nickel is obtainable for the production of austenitic stainless steels for many end uses in defense and defense supporting industries.



THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

FOR BIG, CORROSION-RESISTANT TANKS

HAVEG IS A LOGICAL ANSWER...

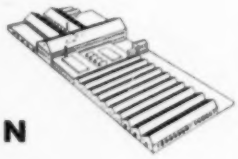


Get what you want with a Haveg-engineered tank. Haveg is not a lining or coating. It is a solid, non-metallic material (resistant to corrosion through and through) that is molded by the Haveg Corporation into tanks as large as 10 feet in diameter by 12 feet in depth. These are single piece, without seams or joints. By joining such sections, even larger tanks can be built. Low cost, with exceptionally long life.

From top to bottom, a Haveg tank has special design features to improve handling acids, bases, salts in your plant. Flat, sloping, cone, dished bottoms are molded to fit your drainage needs. Because Haveg can be machined and repaired on the spot, any change in piping is easily made by your own plant crew.

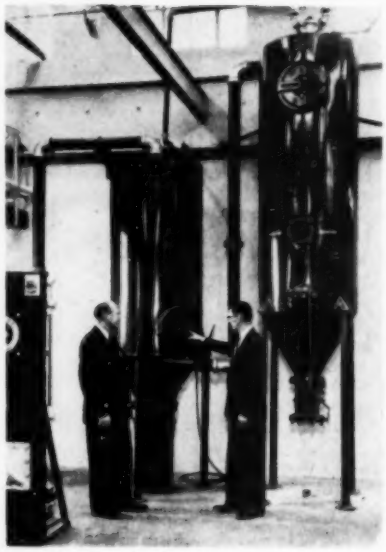
Work with a company that understands how to fight corrosion. Haveg has thousands of molds for any type of chemical handling equipment. Get the complete Haveg story by contacting your Haveg sales engineer and writing for a 64-page technical bulletin (F-6). It shows tank sizes, installation and machining tips, complete chemical resistance tables. Write now . . . for Haveg is a logical answer, both material and engineering-wise, for corrosion-resistant tanks, towers, pipes, valves, fittings.

The Haveg factory is at Marshallton, Delaware (phone Wilmington 3-8884). Capacity has been increased, with deliveries improved. Why take less, when you can get proven, long-life Haveg?



HAVEG CORPORATION
NEWARK 99, DELAWARE

SALES ENGINEERS: Atlanta • Chicago • Cincinnati • Cleveland • Detroit • Hartford
Houston • Los Angeles • Marshallton, Del. • Seattle • St. Louis



Officials of the atomic energy division of Sylvania Electric Products Inc. inspect equipment at the division's new facility at Hicksville, N. Y. The Hicksville project is carrying on the advanced development of new types of materials for use in atomic reactors, or "furnaces," which produce heat through atomic energy. Details of the project are kept secret by A.E.C., except to say that its purpose is to develop materials to enable atomic energy reactors to operate at higher power levels. This could be of importance, for example, in the operation of a nuclear reactor for the production of electric power. Shown here are S. James Higgins, left, engineering manager for operations, and D. Boyd Metz, manager of the Hicksville facility.

KARBATE EQUIPMENT FILM AVAILABLE

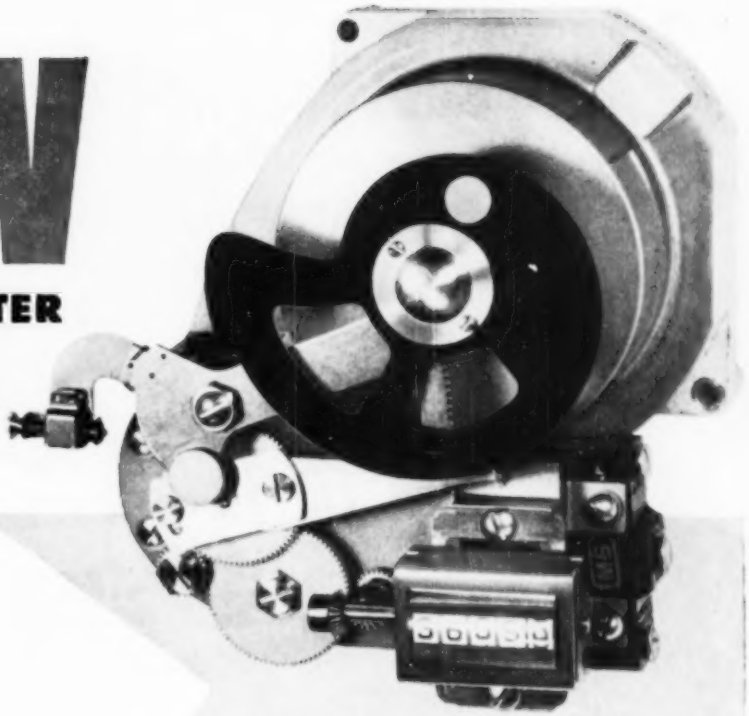
The design and installation of Karbate impervious graphite corrosion-resistant equipment have been demonstrated by National Carbon Co. in two color motion pictures, which may be borrowed from the company's Cleveland office or a district office.

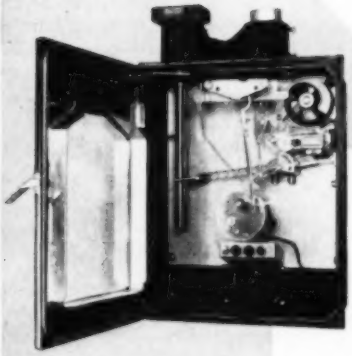
The films, which are aimed at chemical and equipment-design engineers; processing-plant management, superintendents, maintenance and operating crews; and engineering students, are presented as two parts of a complete unit: "Meeting the Challenge" a 14-min. depiction of the experimental and developmental history of Karbate, its physical and chemical properties, and its special applications in modern process industries; "By Way of Experience," running for 12 min., demonstrates installation and maintenance techniques and may be shown alone to plant-maintenance groups as a complete practical training film.

(More News on page 52)

new

FISCHER & PORTER FLOW RATE INTEGRATOR





New . . . and providing a degree of precision never before approached – *plus* Fischer & Porter adherence to quality of design and components . . . the new 1600 Series Integrator merits your careful analysis.

Measure these outstanding benefits:

1. High speed–only 2½ seconds between counts. Follows rapid fluctuations in input signal with highest fidelity.
2. Motor drive – GE type SMY, low speed synchronous motor – absolutely unique in this field.
3. Standard or explosion proof available from stock.
4. Completely enclosed mechanism – new die-cast aluminum case built to meet unusual dust tight, vapor tight, waterproof or explosion proof requirements.
5. All mechanisms completely enclosed, permanently lubricated.
6. Mechanical accumulator – unique F&P design of an infinitely variable roller clutch and reverse brake mechanism, magnetically loaded eliminating springs and friction. Entire mechanism oil immersed for permanent cleanliness, lubrication, and freedom from wear and corrosion.
7. Motor drive gears and overtravel crank enclosed and permanently lubricated with silicone instrument grease.
8. New counter – clearly visible – no peep holes.
   – available with predetermining counters for limiting process quantities.
   – available with reset, remote electric repeater counters.
9. Input cams available for linear, square root or fractional power flow or other functions.

Complete information on the new Series 1600 Integrator is yours for the asking.

FLOWRATOR

FISCHER & PORTER COMPANY

1854-R

130 COUNTY LINE ROAD, HATBORO, PENNA.

Now available

a new improved plastic diaphragm . . .

"L-2" diaphragms offer new high standards of performance in many severe services

For a wide variety of severe services, including the valving of 66° Bé sulfuric acid, the new, improved "L-2" diaphragm offers physical and service characteristics never before available. Like its predecessor, the "L-1", the "L-2" diaphragm is made of polyethylene specially compounded to provide high resistance to strong acids and other highly active materials.

Hills-McCanna diaphragm valves with "L-2" diaphragms are available with a choice of manual, remote or automatic operators and with bodies of any machinable alloy or with rubber, Neoprene, glass or lead linings. Sizes range from ⅜" through 14". "L-2" diaphragms permit operation at temperatures to 125°F and pressures to 100 psi. Other diaphragms available are Kel-F, Neoprene, rubber, Hycar, Tygon, and butyl. Depending on material, these may be used at pressures to 150 psi, temperatures to 220°F.

Write for complete details. HILLS-McCANNA CO., 2438 W. Nelson St., Chicago 18, Ill.

HILLS-McCANNA

saunders patent diaphragm valves

Also Manufacturers of Proportioning Pumps

Force Feed Lubricators • Magnesium Alloy Castings

INDUSTRY CORNERING ENGINEERING TEACHERS

That industry "return to the colleges on a dollar-a-year or lend-lease basis" some of the teachers that it has "lured away in recent years," was suggested by Edwin S. Burdell, president of The Cooper Union, in a recent report on the earning capacity of the school's evening-session engineering students. These students are earning so much that it is difficult, Dr. Burdell said, to attract qualified men to teach them.

Four of the students in The Cooper Union evening session earn from $7,200 to $7,800 yearly, which "approaches closely the maximum salary paid teachers in most colleges." The average annual salary for evening students is $4,214, 8% above last year's figures and 30% above the average two years ago. The highest earnings go to mechanical engineering students (average $4,524), with civil engineering students next ($4,116), then electrical engineering ($3,972) and chemical engineering students ($3,876).

"Without suggesting in any way that industry should begin to deflate engineering salaries, I do believe," continued Dr. Burdell, "that industrial leaders should realize that their material inducements are draining away competent instructors and may, in the near future, aggravate the present shortage of engineers by curtailing our facilities for training through lack of teaching personnel."

SYMPOSIUM TO COVER HEAT, MASS TRANSFER

Recent developments in thermodynamics will be considered at the First Iowa Thermodynamics Symposium, designed for those in the academic field and in industrial research engaged in advanced thermodynamics. It is scheduled for April 27 and 28, 1953 at the State University of Iowa at Iowa City. The symposium will deal especially with processes involving heat and mass transfer. Applications of the discussion topics will be found in the fields of jet engines and other phases of gas dynamics. Further information can be obtained from Dean Francis M. Dawson, College of Engineering, State University of Iowa, Iowa City, Iowa.

FILMS OF A.E.C. AVAILABLE IN PAMPHLET

To answer inquiries on the availability of films pertaining to atomic energy, the U. S. Atomic Energy Commission through its public information service in Washington, D. C., has issued an eight-page pamphlet with films listed for educational, nonprofit, noncommercial

screenings only. The inclusion in this list of other films is for information service purposes only and does not constitute United States Atomic Energy Commission approval. Upon request to Washington, the films (with one exception) are available for short loan periods. The films include "Operation Greenhouse," "Tale of Two Cities."

DIAMOND MAY BUY CHLORINATION PROCESS

Diamond Alkali Co., Cleveland, Ohio, and Belle Alkali Co., Belle, W. Va., announced during February that Diamond has taken a 60-day option either to purchase the stock of the Belle company or acquire the right to use the Belle process for the chlorination of methane.

Under the option agreement, Diamond will pay $275,000 if it elects to acquire the process. If purchase is made, Diamond will pay $1,558,300 if all outstanding shares of the company are acquired.

President Raymond F. Evans of Diamond Alkali explained that the action is an expansion of Diamond's activities in the organic chemicals field. Methyl chloride, methylene chloride and chloroform are derived from the chlorination of methane.

PRINCETON'S PLASTICS PROGRAM AVAILABLE

A 16-page plastics brochure describing the program of instruction and research in plastics offered by the School of Engineering, Princeton University, Princeton, N. J., is now available. This engineering curriculum of graduate study and research leads to the degree of M.S. in engineering, and is particularly suited to chemical, electrical and mechanical engineers, and to chemists and physicists. The primary objectives of the program are instruction and research in application, fabrication, processing and basic properties of high polymers as engineering materials. In addition to research assistantships, Fellowships are also available. Further information is obtainable from Louis F. Rahm, director, Plastics Laboratory, 30 Charlton Street, Princeton, N. J.

CORRECTION

Last month in the Biloxi technical program, "C.E.P." reported that the work leading to the paper "Transport of Momentum and Energy in a Ducted Jet" by L. G. Alexander, A. Kivnick, E. W. Comings, and E. D. Henze, was done at the University of Oklahoma. This is incorrect. According to Lloyd G. Alexander, one of the authors, the work was actually done at the Engineering Experiment Station of the University of Illinois under the supervision of Prof. H. F. Johnstone.

AMERICAN Cyanamid PROVES

Resin-Bonded Glass Laminates Ideal for Alum Applications

PLA-TANK® PRODUCTS MEET THESE EXACTING DEMANDS

Custom molded from polyester resin and glass fiber, a large one-piece unlined tank 14½ feet in diameter by 8 feet high has solved the corrosion attack problem as an evaporator tank in the alum plant of American Cyanamid Company at Mobile, Alabama. Previously a steel tank was used, lined first with lead and then with acid-proof brick. With a pH of three, the hot liquid still attacked these linings with resulting high maintenance costs as well as constant danger of product contamination from the brick.

The process cycle involves loading the tank with alum sulfate liquor at 160° F. raising the temperature to 242° by steam coils in the tank to evaporate the liquor to dryness in four hours.

Many Advantages of New Tanks

Advantages of the new reinforced plastic tank are many and substantial. Cost is less than half the lined steel tank. Weight is under 20% of the lined steel. Corrosive attack as measured on various pilot applications will be negligible over an indefinitely long life.

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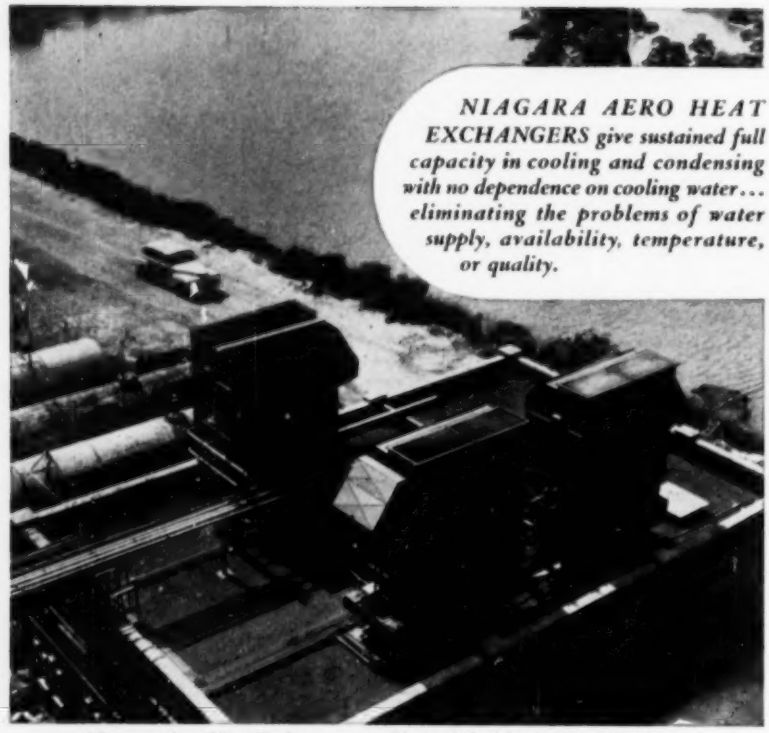
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LOCAL SECTION

The National Capital Section of A.I.Ch.E. and the A.C.S. jointly arranged an interesting dinner meeting in Washington, D. C., on Abe Lincoln night—dinner at Frank & Bernie Restaurant; lecture at the National Museum. The subject of the talk was "Atomic Energy Weapon for Peace" delivered by Prof. Hubert Alyea of Princeton University.

It was good to hear from the Panhandlers and to be able to report here the names of the new officers for 1953. They are as follows: L. A. Webber, chairman; Howard Weaver, vice-chairman; C. M. Kron, secretary; S. J. Marwil, treasurer, and R. E. Weis (ex-officio retiring chairman), H. W. Hennigan and E. W. Henderson, directors.

The Texas Panhandle Section, according to *P. S. Stallings, Jr.*, and *C. M. Kron*, is anticipating a big year in 1953 though it is noted that every month during 1952, with the exception of June, July, and August, speakers addressed the group. This year's activities have already got under way with meetings in both January and February.

To an audience of seventy-six, Kinnon Lilligren of The Emerson Engineers, management counselors, spoke Jan. 20 on "Reducing Maintenance Costs." He explained the scientific approach toward the management of plant maintenance work.

At the Feb. 17 meeting attended by forty-eight members, Messrs. J. N. Poore and C. W. Billings of the General Electric Co. spoke on "The Economics of Future Industrial Power Generation." These men presented the basic theory of gas-turbine operation and application of the gas-turbine principle in industry.

***Lester Berkowitz*, secretary of the Central Pennsylvania Chemical Engineers' Club, has reported that, though he would like to take the credit, he was not the originator of the idea for forming this Club, but that the "driving spirit" was, and is, its present chairman, William E. Keppler of Merck & Co., Inc. To Mr. Keppler our humble apologies for overlooking him in the February Local Section account, and to Mr. Berkowitz our thanks for setting us straight on this matter.**

H. C. McCurdy, secretary of the Knoxville-Oak Ridge Section, has sent in the names of the officers for 1953. They are as follows: W. B. Allred, U. S. Atomic Energy Commission, chairman; John Shacter, Carbide and Carbon Chem. Co., chairman-elect; H. C. McCurdy, Oak Ridge National Laboratory, secretary; R. H. Nimmo, Carbide and Carbon Chem. Co., treasurer; F. N.

Peebles and R. M. Boarts, Univ. of Tennessee, and F. L. Culler, Jr., Oak Ridge National Laboratory, directors.

"Failure to keep you informed on the activities of the Terre Haute Section . . ." Thus S. G. *Bankoff* exonerates this editor from any negligence in writing about the doings of this section in Indiana. He goes on to state that the most recent talk was given by Warren Anderson, Carbide and Carbon Chemicals Co., who spoke on Jan. 29 to an audience of fifty-five on "Coal Hydrogenation." A well-directed color film "Continuous Coal Mining," showing the operations of Carbide's completely automatic seam coal-mining machine, was presented.

At a previous meeting Fred Gruner, Allis-Chalmers Co., spoke about recent developments in atomic energy. This was an "excellent" review of the unclassified literature and was followed by the classic Bikini film "Operation Crossroads."

Congratulations herewith to *Richard C. Berry*, temporary chairman, publicity committee, Eastern Connecticut Chemical Engineers' Club for the Section-in Formation. Everything is pointing up to its success and all hope for a chartering by A.I.Ch.E. Council. Late in 1952 a meeting was held at which the following were elected officers of the Club for 1953. They are: Norman Greenman, Rogers Corp., chairman; Raymond Rosenfield, N.E. Chem. Wks., vice-chairman; Solomon Elmasian, Plastic Film, secretary-treasurer, and David Fields, American Thread, Robert Harlow, Robert Gair, and Richard Berry, Rogers Corp., executive committee members. At this meeting Dr. T. K. Sherwood, professor of chemical engineering at M.I.T., described current research projects going on at M.I.T. The February meeting featured a talk on statistical methods by Prof. Geoffrey Beall of the department of mathematics at University of Connecticut, while in March a joint meeting with the New London Section, A.S.M.E., will be held.

O. J. Britton of the Pfaudler Co. addressed the Louisville Section on Feb. 10 at the Speed Scientific School Auditorium on glass-lined steel equipment. Mr. Britton is on the technical staff of a leading designer and builder of this equipment. The month previous Claude Durgee, chemical plants division, Blaw-Knox Co., gave a talk titled "Plant Layout."

H. H. Sineath, reporter for the Atlanta Section, has come through with an account of recent activities of that section which held its first meeting of 1953 on Jan. 27 in Brittain Dining Hall on the Georgia Tech Campus. Thirty-seven members and guests attended. The newly elected officers for 1953 were installed as follows: F. Homer Bell, chairman; Frederic Bellinger, vice-chairman,

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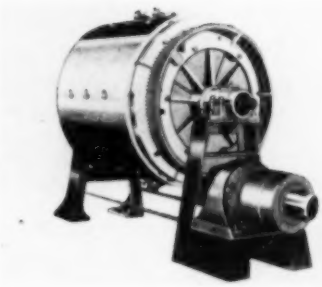

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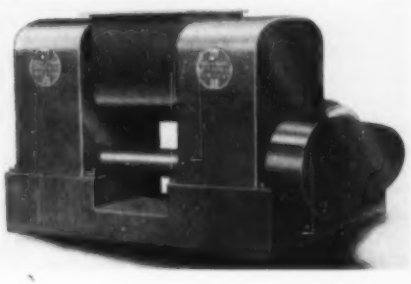

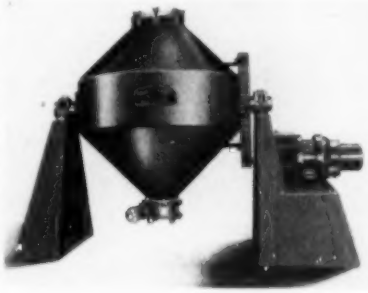

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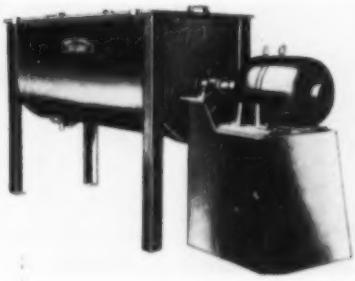

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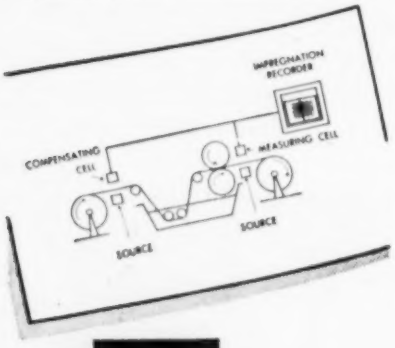

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and J. E. Ross, secretary-treasurer. The executive committee consists of the following members: J. N. Carothers; Herschel H. Cudd; Edward M. Jones; Frank P. LaBelle, and E. H. Conroy, ex officio.

After the business session Curry E. Ford, carbon production division, National Carbon Co., discussed briefly his work as chairman of the Institute's Sections Committee. He followed with a talk on the use of Karbate process equipment.

The fourth and fifth meetings of the 1952-53 fiscal season of the Philadelphia-Wilmington Section were held on Jan. 13 and 20, the first at the Rodney Hotel, Wilmington, and the latter at School Lane House, Philadelphia.

The Wilmington meeting, attended by about 135 persons, featured a talk on "World Oil Resources" by A. H. Chapman, American Arabian Oil Co. The meeting was concluded with the showing of a sound-color film "Desert Venture."

The Philadelphia meeting, with about eighty members attending, featured three speakers:

E. Neil Helmers, Du Pont—*Air Pollution Control in the Chemical Industry.*

N. K. Chamberlain, Philadelphia Air Pollution Control Board—*What Philadelphia Is Doing on Air Pollution.*

Jesse Lieberman, an industrial chemical engineer for the City of Philadelphia, demonstrated various instruments the city uses in its control work.

A meeting of the executive committee of the Cleveland Section was held Jan. 21. *Wilfred H. Charbonnet*, the 1953 secretary, states that many subjects and topics were discussed at this meeting, such as a talk to be given by representatives of the Harshaw Chemical Co. at the Ohio-Pittsburgh Symposium on Fat and Oil Industries in Cincinnati in April; also a liaison with the Painesville-Ashtabula area and the possibilities of a plant trip to that area later in the spring. Officers for 1953 are as follows: A. J. Teller, chairman; H. G. Metzger, chairman-elect; R. G. Atkinson, treasurer, and W. H. Charbonnet, secretary.

According to *D. F. Rynning*, publicity chairman, Northern California Section, the new year had an auspicious beginning when more than 100 members and guests attended the January meeting at the Engineers' Club, San Francisco. The speaker C. T. Butler, works manager of the Hercules Powder Co. plant, Hercules, Calif., discussed the general subject of dynamite. He briefly covered its history, the manufacturing process, and various aspects of its economic importance. He also pointed out some of the recent developments in the industry.

L. C. Palmer of the Maryland Section reports that a good attendance marked the Jan. 20 meeting when the President of A.I.Ch.E., W. T. Nichols, was the principal speaker at the Baltimore Engi-

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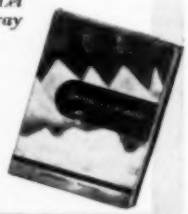

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neers' Club. Mr. Nichols talked about the Institute and its work. A meeting was held on Feb. 17 when Charles M. Cooper addressed the Section on the subject of mathematics in engineering research.

The speaker for the Feb. 19 meeting of the Nashville Section was Harold L. Jacobs, whose subject was trade waste disposal. *R. A. Nance*, secretary-treasurer of the Section, reports that Mr. Jacobs has been actively engaged as a consultant on trade waste disposal for the Du Pont Co. for more than fifteen years and was therefore able to draw on his wide experience for illustrative examples.

A. T. Pickens and *R. G. Kerlin* report that a talk was given before the St. Louis Section Feb. 17 on the language of computers, analog vs. digital machines, computers vs. human brains, computers as engineering tools, etc. It was Lee Ohlinger, chief of the computing service at Northrop Aircraft, who spoke that language. He is at present serving as consultant to the A.E.C. and to the Union Electric-Monsanto Atomic Energy Project.

This Section is already on the qui vive over the December meeting. Charles W. Swartout, Mallinckrodt, chairman of the 1953 National A.I.Ch.E. meeting, reported that about 2,000 are expected.

The Brass Rail (Fifth Avenue) must appeal to New York Section members for they are going back there on March 19 for a 6 o'clock dinner and to hear a talk on small chemical business. So says *Bernard H. Rosen*, section reporter.

Dr. T. F. Reed, research associate, research and development laboratory, U. S. Steel Corp., spoke with firm belief in his subject. "Opportunity for the Chemical Engineer in Steel Industry Research," to approximately sixty members and guests of the Pittsburgh Section at the Section's fifth dinner-meeting of the 1952-53 year held at the Royal York Apartments on Feb. 4.

The prominent role chemical engineering and chemical engineers play in the making, shaping, and treating of steel constituted the underlying theme of Dr. Reed's talk. This review according to *J. R. West, H. A. Morrissey*, and *J. H. Black*, reporting on the affair, served to demonstrate where chemical engineering unit operations are used to full advantage in the steel industry.

A. G. *Smith* has reported that the Boston Ichthyologists (J. Edward Vivian, Kingfish) held a regular meeting Jan. 23 at which Wentworth Brown, vice-president of the Brown Paper Co., Berlin, N. H., discussed some of the history and trends of the pulp and paper industry. His talk

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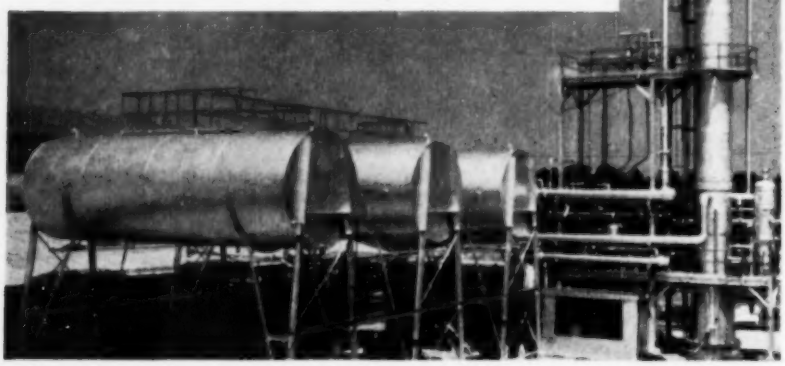

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Two members of the Northeastern New York Section were co-recipients of a Coffin Award bestowed by the General Electric Co. for their "imaginative conception and definite development of a novel and useful contactor for liquid-liquid extraction." The equipment is being utilized on a production scale by the Atomic Energy Commission. *Harry H. Steinhauser, Jr.*, secretary of the section, expresses the pride of the section in these two members—B. V. Coplan and J. K. Davidson.

The sixth meeting of the Section was held Feb. 10 in Schenectady at the General Electric Co. John A. Rumsey, plant accountant of General Aniline Works in Rensselaer, spoke on "Financial Considerations of New Capital in the Chemical Industry," to the thirty members present.

Norton C. Foster, technical sales representative, Dow Corning Corp., spoke on "Silicones in Industry" before members of the New Jersey Section on Jan. 13, 1953, in the Bakelite Corporation Auditorium, Bound Brook, N. J., at 8:00 P.M. *Lysle J. Heney*, publicity committee, New Jersey Section, reported that the talk aroused considerable interest.

Mr. Foster has had experience in the product development laboratories in the Dow Corning plant in Midland, Mich. Prior to going to Dow Corning he was with the Calumite Co. and Owens-Illinois Glass Co.

There's interesting news elsewhere in this issue about the one-day meeting of this Section (See page 27).

The Midland (Mich.) Section has been conspicuously silent but a long account of its activities from September, 1951, when it held its first organizational meeting, through December, 1952, has been received. It is only since November, 1952, that Midland has been officially a bona fide local section of A.I.Ch.E. During the year just ended ten meetings had been held featuring outside speakers on such subjects as: drying, power from the atom, plant evaluation and financing, with estimated attendance averaging more than 100 at each meeting. The Section also actively cooperated with the educational department of the Dow Chemical Co. and with other technical societies in Midland in providing courses in chemical engineering for personnel in the area. *John H. Wardell*, secretary-treasurer, states that J. W. Corey, as chairman, will head the Section in its first year as a local section of the Institute. Wardell's report augurs well for the success of this section.

Thanks to *E. H. Vause*, editor, Chicago Section Newsletter, or whoever was good enough to send us, as per our request, copies of the News-

letter for our perusal. We were interested in a new ruling from this section, namely, editorials in Newsletter should be limited to those having a bearing on chemical engineering. Other information forwarded us included the scheduling of the talk by W. H. Williams of the Dow Chemical Co. on outdoor plant construction. Mr. Williams' plan is to relate some of Dow's experiences with outside plant construction.

A. M. Holzberg, technical press representative of this section, sent in word that at the January meeting Edward M. Blair, a partner in William Blair and Co., investment bankers, covered the procurement of new capital for big, medium, and new concerns. The speaker gave some attention to the unique function served by investment bankers in attracting risk capital to new but soundly conceived business.

At Charleston, W. Va., Section, L. V. Sherwood talked on Feb. 24 in the Charleston Recreation Center on the subject of soil conditioners. He is manager of the agricultural chemicals section of Monsanto organic chemicals division development department. *A. G. Draeger* reported that at the January meeting the speaker of the evening, Prof. J. C. Whitwell of Princeton University, discussed "Statistical Methods in Chemical Engineering Problems." He pointed out that the application of statistics to chemical engineering problems was a fairly recent development and stated further that proper use of statistics could reduce the risk involved in making engineering decisions and could improve the efficiency of experimentation.

The following are the new officers of the Central Ohio Section for 1953: C. J. Geankoplis, The Ohio State University, chairman; K. S. Jacobs, Ironsides Co., vice-chairman; R. B. Filbert, Jr., Battelle Memorial Institute, secretary-treasurer; R. C. Crooks, Battelle Memorial Institute, membership chairman; and G. F. Sachsel, Battelle Memorial Institute, publicity chairman. The following are on the Executive Committee: W. J. Maidens, American Zinc Oxide Co., J. W. Clegg and C. E. Dryden, Battelle Memorial Institute. At a dinner meeting on the campus of the Ohio State University on Jan. 27, 1953, Lee Moore, transmission engineer, Columbus and Southern Ohio Electric Co., discussed "Future Power Trends in Ohio and the United States."

Thirty-five members of the Western New York Section assembled at the Hotel Sheratan to hear D. C. Lee, Jr., describe the experience Celanese has had with perforated plate distillation columns. There was an active discussion period after the talk in which actual design details were discussed. *J. W. Casten*, reporter, states that at the March 12 meeting A. J. P. Wilson described chemical engineers in the economics of market research.

Lyman Cox, a member of Western New York Section, is panel chairman of the Air Pollution Panel for the Industrial Conference scheduled for April 23.

—H.R.G.

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MEETINGS

Toronto, Canada (See page 17).

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.

Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

Washington, D. C., Statler Hotel, March 8-10, 1954.

Technical Program Chairman: George Armistead, Jr., Consult. Chem. Eng., George Armistead & Co., 1200 18th St. N.W., Washington 6, D. C.

Springfield, Mass., May 16-19, 1954.

Ann Arbor, Mich., Univ. of Mich., Ann Arbor, Mich. June 20-23, 1954—Conference on Nuclear Engineering.

Technical Program Chairman: D. L. Katz, Chairman, Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich.

Glenwood Springs, Colo., Hotel Colorado, Sept. 12-16, 1954.

Annual—New York, N. Y., Statler Hotel, Dec. 12-15, 1954.

Technical Program Chairman: G. T. Skaperdas, Assoc. Dir., Chem. Eng. Dept., M. W. Kellogg Co., 225 Broadway, N. Y. 7, N. Y.

Asst. Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

SYMPOSIA

Ion Exchange
Chairman: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.
Meeting—San Francisco, Calif.

Mixing
Chairman: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill.
Meeting—San Francisco, Calif.

Transport Properties
Chairman: J. L. Franklin, Res. Assoc., Humble Oil & Refining Company, Baytown, Texas
Meeting—San Francisco, Calif.

Applied Thermodynamics
Chairman: W. C. Edmister, Calif. Res. Corp., 576 Standard Ave., Richmond, Calif.
Meeting—San Francisco, Calif.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. Chem. Eng., Univ. of Washington, Seattle, Wash.
Meeting—San Francisco, Calif.

Distillation
Chairman: D. E. Holcomb, Dean of Eng., Texas Technological College, Lubbock, Tex.
Meeting—St. Louis, Mo.

Dust and Mist Collection
Chairman: C. E. Lapple, Dept. of Chem. Eng., Ohio State University, Columbus 10, Ohio.
Meeting—St. Louis, Mo.

Drying
Chairman: L. E. Stout, Dept. of Chem. Eng., Washington University, St. Louis 5, Mo.
Meeting—St. Louis, Mo.

Use of Computers in Chemical Engineering
Chairman: John R. Bowman, Head, Dept. of Res. in Phys. Chem., Mellon Institute of Industrial Research, Pittsburgh 13, Pa.
Meeting—St. Louis, Mo.

Heat Transfer
Chairman: D. L. Katz, Chairman (Address: See Ann Arbor Meeting).
Meeting—St. Louis, Mo.

Liquid Entrainment and Its Control
Chairman: H. E. O'Connell, Esso Corp., P. O. Box 341, Baton Rouge, La.
Meeting—St. Louis, Mo.

Carbonization
Chairman: R. S. Rhodes, Asst. Mgr., Prod. Dept., Koppers Co., Inc., Koppers Bldg., Pittsburgh 19, Pa.
Meeting—St. Louis, Mo.

Industrial Waste Disposal
Chairman: R. D. Hoak, Sr. Fellow, Mellon Inst., Pittsburgh 13, Pa.
Meeting—St. Louis, Mo.

Nuclear Engineering
Chairman: D. L. Katz, Chairman (Address: See Ann Arbor Meeting).
Meeting—Ann Arbor, Mich.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Loren P. Scoville, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, P. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 120 days before a meeting cannot be considered.

PEOPLE

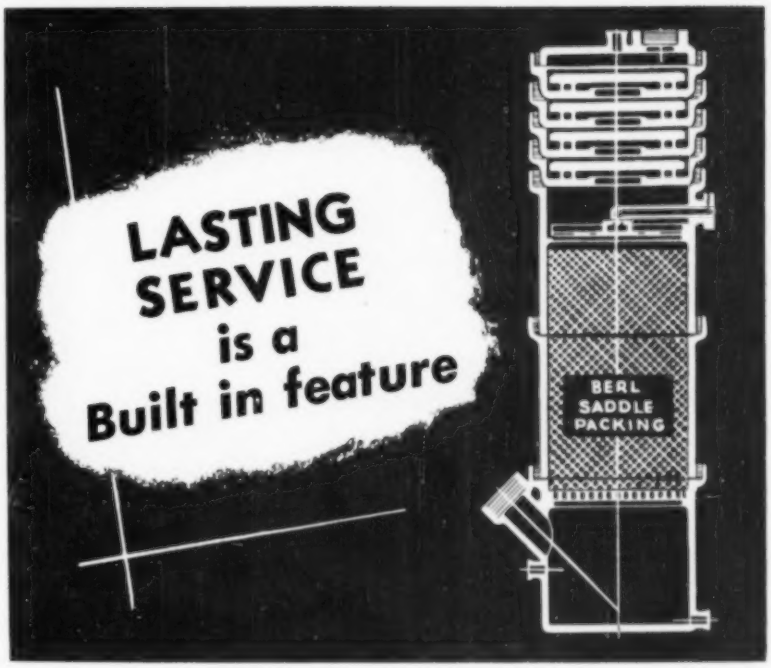
Thomas H. Chilton, technical director, engineering department, Du Pont Co., was recently named chairman of the Engineering Manpower Commission, Engineers Joint Council. He succeeds in this capacity Carey H. Brown.

Dr. Chilton was President of the American Institute of Chemical Engineers in 1951 and has worked on numerous committees including the Publications, and Student Chapters. He has received many awards and honors, such as a certificate of service from the American Standards Association in recognition of his work in the development of American standards, and a University Medal for Excellence bestowed by Dwight D. Eisenhower, president of Columbia University in 1950.

F. W. ZUR BURG ON LOUISIANA BOARD

Frederick W. zur Burg, head of the department of chemical engineering, Southwestern Louisiana Institute, Lafayette, La., was recently appointed to the State Board of Registration of Professional Engineers in Louisiana. Dr. zur Burg received his Master's degree from the University of North Carolina in 1928 and a Ph.D. in 1943 from the Virginia Polytechnic Institute. He has served as consultant to the U. S. Department of Agriculture and to the United Corps of Engineering of Louisiana, and was assistant instructor to the head of the department of chemical engineering at Clemson College in 1942.

George Granger Brown, dean of the College of Engineering, University of Michigan, Ann Arbor, and a former President of American Institute of Chemical Engineers, was elected a director of Nash-Kelvinator Corp. at that company's annual meeting on February 6 in Detroit. In 1950 Dr Brown was named director, U. S. Atomic Energy Commission division of engineering, and in this capacity specifically was concerned with the chemical engineering phases of the A.E.C.'s reactor development program. Dr. Brown was the winner of the Institute's Walker Award in 1939.



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The sectional tower pictured above is of a type used for drying chlorine with sulphuric acid. It is made of Knight-Ware Chemical Stoneware, a corrosion-proof material which offers several important advantages.

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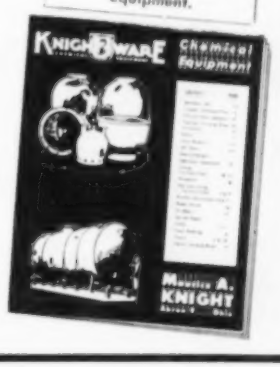

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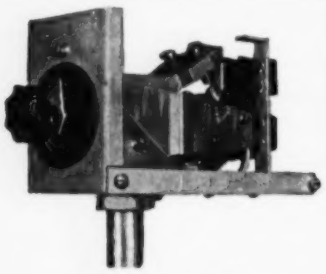

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Gustav Egloff, petroleum scientist and director of research for Universal Oil Products Co., Des Plaines, Ill., since 1917, has won the Washington Award for 1953 "for distinguished leadership in petroleum research and development in professional activities and in community services."

Fabian Bachrach

Early in his career Dr. Egloff was associated with the Bureau of Mines, and Aetna Chemical Co. A graduate of Cornell University, Dr. Egloff received his Ph.D. degree from Columbia University in 1915. He has served as president of the Western Society of Engineers, American Institute of Chemists and the Chicago Technical Council. The Washington Award was founded in 1916 by John Watson Alvord.

David Fulton has been recalled by the Lummus Co., New York, to take up his newly appointed position of assistant to the president. Prior to recall, Mr. Fulton was for a number of years manager of Lummus' French affiliate, Société Française des Techniques Lummus, in Paris.

Karman Duchon has been appointed vice-president of DuMac Construction, Inc., Cleveland, Ohio. His duties include construction management and direct supervision. Mr. Duchon was formerly a chemical engineer with Standard Oil Company of Indiana at Whiting, Ind.

Kenneth H. Klipstein, assistant general manager and head of the technical department of Calco Chemical Division of American Cyanamid Co., Bound Brook, N. J., has been announced as the 1953 medalist for the annual award conferred by the Commercial Chemical Development Association for outstanding accomplishment in commercial chemical development. Mr. Klipstein spent seven years in research with E. C. Klipstein & Sons, Inc., joining them in 1924 with a Master's degree in chemistry received from Princeton University that year. His career with Calco began with the merger of Klipstein with Calco Chemical Co. in 1933. In March, 1951, Mr. Klipstein became associated with N.P.A. In 1952 he returned to Calco in his present capacity.

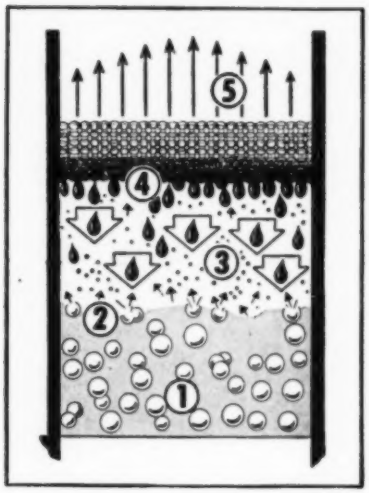
(Advertisement)

Pads of Knitted Wire Mesh Wipe Out Liquid Entrainment

Removal of the liquid carry-over which is present in a wide range of processing operations is being secured, effectively and economically, by using pads made from multiple layers of knitted wire mesh.

These pads combine, within a few inches of depth, large wire surface area with an unusually high free volume—97 to 98%—made up of a multiplicity of unaligned asymmetrical openings. Installed within a vessel, these pads offer minimum restriction and pressure drop, yet it is impossible for a gas to pass through without continually changing direction and forcing impingement of the entrained liquid droplets upon the wire surface.

How These Pads Work



A gas generated in or passing through a liquid (1), carries with it, as it bursts from the liquid surface (2), a fine spray of liquid droplets. These entrained droplets are carried upward by the rising gas stream (3).

As this gas passes through the pad, the droplets impinge on the extensive wire surface (125 square feet per cubic foot of pad volume). Droplets accumulate on the wire surface and form large drops of liquid which break away (4) from the wire mesh and fall back against the gas stream. The gas (5) passes on, freed from liquid entrainment. The liquid is returned.

Availability

Since these pads, known as METEX MIST ELIMINATORS, can be knitted of practically any metal or alloy available in wire form, effects of corrosion can be minimized. A builetin giving detailed information is available on request from the manufacturer, Metal Textile Corporation, Roselle, N. J.

Appointment of **Hugo Klein** as general sales manager of the A. E. Poulsen Co., Los Angeles, engineers and manufacturers of materials-processing and handling equipment, has been announced. Mr. Klein, who holds engineering degrees from Columbia University, brings to his new position twenty-four years of diversified administrative and consulting experience in industry. His new responsibilities will include coordination of sales of all types of equipment manufactured and distributed by the A. E. Poulsen Co.

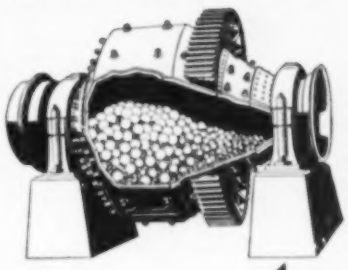
Richard M. Hoover, a member of central purchasing department, Monsanto Chemical Co., has been assigned to the purchasing department of the company's organic chemicals division in St. Louis, Mo. He has been with Monsanto since 1947. He was assistant supervisor in the company's John F. Queeny plant in St. Louis when he joined the central purchasing department last year.

Harry J. Karakas, who recently joined the Pfaudler Co., has been appointed a field promotional engineer. In December, 1952, he took charge of the Washington sales office of Pfaudler and will extend his sales engineering assistance to other areas in the East.

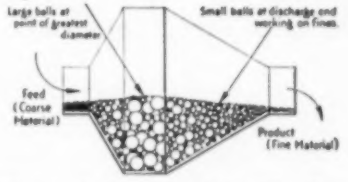
Robert L. Bates, formerly chief engineer, process equipment division, International Engineering, Inc., Dayton, Ohio, is cofounder and president of Chemineer, Inc., a newly formed company. Chemineer will manufacture special agitating and mixing equipment for the processing industries.

Judson G. Brown is now associated with Virginia-Carolina Chemical Corp. as chemical engineer. He received his B.S. degree in chemical engineering from the School of Engineering, University of Michigan in 1944. Prior to joining the Virginia firm, he was associated with the International Minerals and Chemical Corp. where he served as section leader in charge of an Atomic Energy Commission project. His other experience with A.E.C. work includes service with the Du Pont Hanford Works, Washington, and with General Electric, where he was employed in design and construction work on A.E.C. projects.

HARDINGE CONICAL MILL



FOR BALL SEGREGATION, STILL TOPS!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The conical shape of the Hardinge Mill causes a rapid circulating and classifying action within the drum, which increases the capacity for power expended over other types. The range of grinding is large, due to the segregation of the sizes within the mill. The conical shape insures extreme rigidity and simplicity. Mechanical troubles are practically unknown. Sizes range from 2 feet to 10 feet with capacities from a few pounds per hour to 100 tons per hour. Bulletin 17-B-40 gives full details of dry grinding applications: Bulletin AH-389-40, wet grinding.

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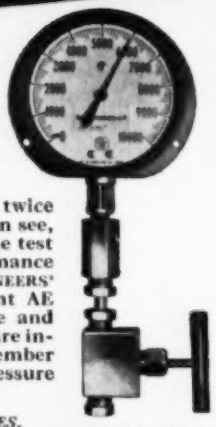

This valve was photographed twice . . . 30 days apart. As you can see, pressure was constant over the test period. Dependable performance is typical of AUTOCLAVE ENGINEERS' products. Another important AE feature is service. The valve and all fittings used for the test are in-stock items. A point to remember when you think of high pressure equipment.

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Henry F. Peters, formerly project manager, has been promoted to director of engineering in charge of project and production engineering for the engineering division of the Scientific Design Co. Mr. Peters joined Scientific Design Co. in 1948 and served as project manager until his present promotion. Previously he served as mechanical engineer and later as process design engineer for the M. W. Kellogg Co. Prior to that Mr. Peters was with the Du Pont Co. as field engineer in the chemical plant construction division.

PERSONNEL CHANGES AT GENERAL ANILINE

Personnel recently transferred to administrative posts in the newly established process engineering department and semi-works, Grasselli plant, General Aniline & Film Corp., Linden N. J. are: **Walter N. Alexander,** supervisor of the planning section. He was first employed by General Chemical Co., New York as a junior engineer, later advancing to the post of chemical engineering assistant to the director of operations. In April, 1946, he went to the General Aniline. He was appointed assistant chief designer of the engineering department, and when the chemical engineering department was established five years ago he was named manager.

Clyde McKinley, superintendent, process engineering section. Dr. McKinley was employed for two years as a chemical engineer by a Michigan public utility holding company; he resigned to accept a fellowship at the University of Michigan, where he received a doctor's degree in chemical engineering in 1943. He joined Aniline at its Easton laboratories that year, and four years later was named a research section leader. He also served as plant engineer there until he transferred to Grasselli as a chemical engineering assistant. A year ago he was appointed production supervisor of the special products area.

Charles F. Montross and **Herman H. Tiedemann** have been named supervisors under Dr. McKinley, the former in the process evaluation group and Mr. Tiedemann in the development group. Mr. Montross, a native of France, has been associated with the faculty of Brooklyn Polytechnic for more than six years, first as a part-time instructor in chemical engineering and now as an adjunct professor in the Graduate School. Employed by General Aniline in January, 1949, he was appointed supervising chemical engineer in the special prod-

ucts area a year ago. Mr. Tiedemann served three years as a teaching member of the faculty, University of Pennsylvania. He was assistant pilot plant superintendent of Rohm & Haas, Philadelphia, when he resigned to join General Aniline as a senior chemical engineer in June, 1948. He was appointed a supervisor in 1949.

George G. Crewson has recently been appointed technical consultant to the administrative staff of the chemical divisions, Food Machinery & Chemical Corp., N. Y. Technical consultant in the office of the chief of Chemical Warfare Service at Washington during World War II, Mr. Crewson has for the past decade been director of engineering, Buffalo Electro-Chemical Co. in charge of engineering, construction and process improvement in connection with hydrogen peroxide processes used in the company's plants. He will continue in his present post at Buffalo Electro-Chemical Co. but will also be available for consultation by all FMC divisions and plants.

The appointment of **Sidney P. Thomes** as a chemical engineer to the Monsanto Chemical Co.-Union Electric Co. of Missouri atomic electric project was recently announced. He had been on leave of absence from Monsanto since September, 1951, as a member of the Westinghouse Electric Co.'s atomic power division at Pittsburgh, Pa. Thomes went to Monsanto in June, 1941, and was first employed in the operating department at Anniston, Ala. In 1946, he became assistant plant engineer and in 1951, when he left for Westinghouse, he was acting chief chemical engineer for the phosphate division at Anniston.

Hugh F. Colvin was recently promoted to the position of vice-president and treasurer of Consolidated Engineering Corp. Upon graduation from the California Institute of Technology in 1936 with a B.S. degree, he joined the American Gas Association as a chemical engineer. Returning two years later to his academic training, he attended the Graduate School of Business Administration at Harvard University and, in 1939, was awarded his M.B.A. degree with distinction. After leaving Harvard, Colvin was associated with the Wilshire Oil Co. as a chemical engineer, following which, in 1940, he became affiliated with the Union Oil Co.

(*Continued on page 67*)

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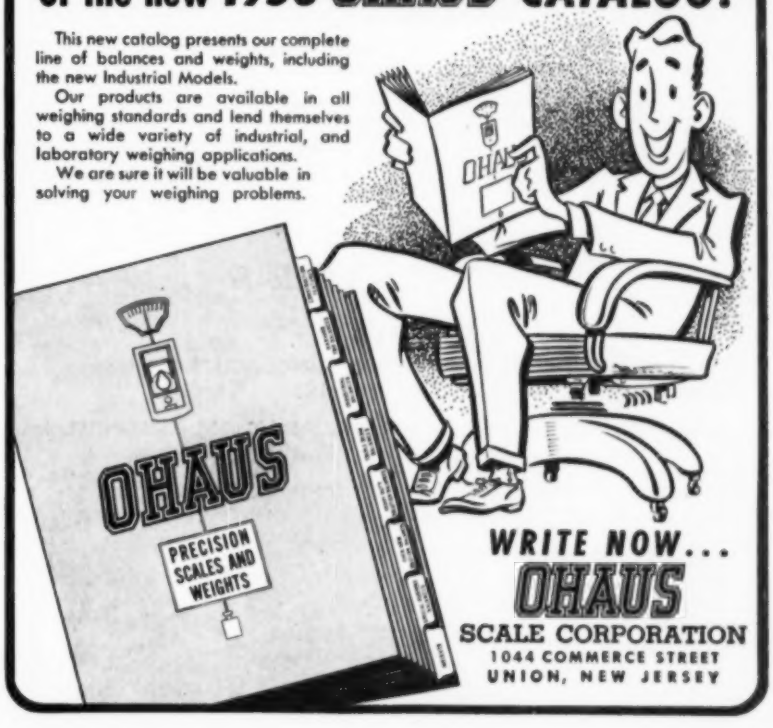

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PROJECT MANAGER

Chemical or mechanical engineer with heavy experience all phases design chemical or oil plants, capable of administering and guiding projects from inception through various specialist departments; deal directly with client as the principal coordinator and administrator on the specific job, for engineering company, Metropolitan New York. Should thoroughly understand mechanical and structural aspects as well as chemical; operating experience helpful. Permanent position of great opportunity for top-notch man only, since little time for training. Must be flexible and able to fit into growing progressive organization's methods. Full details first letter. Box 4-3.

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CHEMICAL ENGINEER—Age 28 to 35, for pilot plant, process development and process demonstration work. Experience required preferably in petroleum refinery operations or process design. Location Middle West. Salary commensurate with experience. Box 6-3.

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CHEMICAL ENGINEER—With four years' experience in production (department head), three years' experience in trouble shooting, equipment design, installation and maintenance (now assistant plant engineer). Would like to change to a more responsible position in production, preferably in company with incentive arrangement. Age 34, married. Box 10-3.

CHEMICAL ENGINEER — Desire development, consulting position. Associated seven years in successful chemical-textile process design and development. One year assistant consultant for equipment design pumps, pressure dispensers; process and food plant design. M.S. in Ch.E. Single, 30. Will travel. Three forthcoming publications: physical properties of starch conversion products and heat transfer equipment performance. Box 11-3.

M.S.Ch.E.—Project engineer, five years. Design and specification of chemical processing units from development data, organic field. Experienced in supervision of construction and drafting personnel, purchasing and contract negotiations. Veteran, 27, married. Box 12-3.

CHEMICAL ENGINEER — MANAGEMENT — B.Ch.E. and B.S. in Business Administration. Active member of A.I.Ch.E. Eight years' diversified supervisory experience as project engineer and technical advisor in dyes and pigments, textiles, plastics (calendered, cast, extruded and coated) from development through production stages. Veteran, single. Spanish, some French and German. Desire responsible position in technical liaison or management. Box 13-3.

CHEMICAL ENGINEER—M.S.Ch.E. 28, married, veteran. High academic standing, several years' experience in organic synthesis, now supervisor in Eastern company. Seeking position with advancement opportunities to utilize engineering training to utmost. Minimum $6,800. Box 14-3.

CHEMICAL ENGINEER—Ph.D., P.E. Age 34, family. Eight years teaching, consulting, and industrial work. Experience includes process design and economic studies. Excellent thermodynamic background. Desire responsible industrial or teaching position. Present earnings $8,500. Box 15-3.

SALES, MARKET RESEARCH OR DEVELOPMENT—B.Ch.E. (Five years) 1950. Age 27. 1½ years application research industrial and agricultural chemicals. 1½ years sales, market research and development process equipment. Box 16-3.

CHEMICAL ENGINEER—Ph.D. Age 30, married. Five years' industrial, research, and teaching experience. Desire academic position with research and consulting opportunities. Position on twelve-month basis preferred. Available June or September 1953. Box 17-3.

CHEMICAL ENGINEER — B.Ch.E. 1941. Twelve years' experience in organic chemical process design including economics and cost estimation of experimental and commercial plants. Successful record of responsible administration and supervision of pilot plants. Age 42. Married. Box 18-3.

CHEMICAL ENGINEER—M.S. 1949. Age 26. Married, family. Three years' varied process engineering experience; pilot plant operation, plant start-up, and cost estimation. Desire responsible position with progressive company. Prefer Midwest or Southern location. Box 19-3.

TROUBLE SHOOTING, PRODUCTION, PROCESS AND EQUIPMENT DEVELOPMENT—Ten years' experience, mostly inorganic. Three years Navy electronics. B.Ch.E. 1940. Desire to use experience on job offering more opportunity. Box 20-3.

PRODUCTION MANAGER — 46. Registered chemical engineer. Twenty years' experience chemical plants including fourteen years production management. Desire production supervision or purchasing. Salary secondary to pleasant association and opportunity to establish reasonably permanent home. Box 21-3.

ADMINISTRATIVE CHEMICAL ENGINEER—Registered P.E., age 37. Experienced production, plant, general superintendent, production manager. Fifteen years chemical plant administrative experience in alcohol, whiskey, rayon-cellophane, fertilizer, sulfuric acid, soybean oil solvent extraction, submerged fermentations, riboflavin, Vitamin B-12. Also interested other fields. Very adaptable. Box 22-3.

INDUSTRIAL ADVERTISING OR MARKET RESEARCH—Chemical engineer (B.S. University of Michigan). Age 28, single. With six years' experience in production, research and development on organic chemicals. Desire to utilize this experience in the field of industrial advertising or market research. Have aptitude and great interest in technical writing and in contact work. Box 23-3.

CHEMICAL ENGINEER—Ph.D. 1951, minor in petroleum engineering. Married, family, veteran. Three years' teaching experience, two years' experience in petroleum production research. Desire responsible position with future. Present salary $7,000. Box 24-3.

CHEMICAL ENGINEER — B.S. 1946, M.S. 1951, University of Southern California. 29 years old. Married. Experience in rubber. Diversified experience in production and pilot plant operation. Responsible. Production or design work desirable. Prefer West Coast location. Alien. Box 27-3.

CHEMICAL ENGINEER—M.S. 3½ years' process development experience. Desire position in development or design in the New York City area. Box 28-3.

Nonmembers

CHEMICAL ENGINEER—Age 42. Experienced in process development, desire permanent connection with small or medium-sized company. Challenging position and opportunity for advancement essential. Presently in charge of forty chemical and mechanical engineers plus shift organization, carrying on pilot plant operations, process evaluation, heat transfer studies and equipment structural analysis. Résumé on request. Box 25-3.

SALES ENGINEER—B.S. in Ch. Engr. Experience in plant design. Now selling industrial controls to chemical and oil industries. Would like position as sales engineer selling chemical plant equipment or chemicals. Present salary $500 a month. Write Box 26-3, Chemical Engineering Progress.

PEOPLE

(Continued from page 65)

The promotion of **C. H. Kollenberg** to assistant division head has been announced by technical service division of Baytown, Tex., refinery, Humble Oil & Refining Co. Dr. Kollenberg joined the organization in 1940, going from the University of Texas where he received his Ph.D. in chemical engineering in 1939. The intervening year was spent as a graduate fellow at the university. He has been a section head for the past eight years, specializing in cracking and hydroforming. Recently he has handled assignments involving long-range planning of refinery installations.

The following staff additions to the technical service division were also announced: **William G. Domask**, a Ph.D. in chemical engineering, the University of Texas, and **William A. Burrell** formerly with Buckeye Cotton Oil Co. **James F. Mathis**, a Ph.D. in chemical engineering, the University of Wisconsin, was assigned to the research and development division.

James G. Bronson has been named divisional sales manager in charge of alkalis and **Fritz von Bergen**, formerly in charge of the market development section, technical sales division, is now manager of the barium chemicals division. Westvaco Chemical Division, Food Machinery and Chemical Corp. Bronson had previously been divisional sales manager for barium and miscellaneous chemicals and assistant divisional sales manager of magnesias.

Irwin E. Brussel-Smith formerly a piping design engineer and process tower design engineer with the M. W. Kellogg Co. is now employed by the Foster Wheeler Corp., New York, as a job engineer. He received his B.Ch.E. degree from the Polytechnic Institute of Brooklyn.

Wilfred Gains, a graduate of McMaster University, Hamilton, Ont., Canada, was recently appointed to the staff of the Vulcan engineering division, Vulcan Copper & Supply Co., as project engineer. For the past twelve years he has been associated with Chemical Construction Corp., New York.

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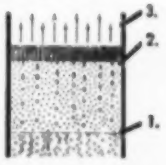

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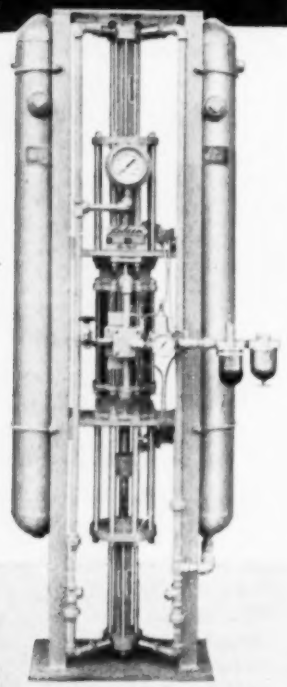

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Richard G. Powell, a technical service representative for Spencer Chemical Co., has been transferred to the Spencer North-Central office in Chicago to act as technical service representative for the North-Central district. He had been in the executive and general sales offices in Kansas City. He became associated with the company in January, 1952. Mr. Powell received his B.S. degree in chemical engineering from Iowa State College in 1951.

Necrology

L. H. BARTLETT

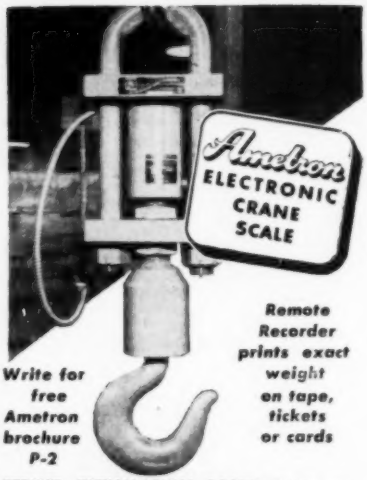
Luis H. Bartlett, head of the chemical engineering department, Oklahoma A. & M. College, died recently. He was 58 years old. Before going to Stillwater, he was director of the Louisiana State University Engineering Experiment Station. From the University of Tennessee, Knoxville, he received the degrees of Bachelor of Science (1934) and Master of Science (1935), and a Ph.D. from the University of Texas (1943). He was employed jointly from 1934 to 1939 by the Tennessee Valley Authority and University of Tennessee Engineering Experiment Station, and subsequently served as assistant professor of mechanical engineering with the University of Texas, later as associate professor and member of the graduate faculty. He was at one time with the McEvoy Co., Houston, Tex., as research and development engineer.

L. D. VORCE

LaFayette Denton Vorce inventor of the Vorce cell for the manufacture of chlorine, died recently. Since 1927, and until his illness, he was associated with the Westvaco division of the Food Machinery and Chemical Corp., New York. A graduate of the Case School of Applied Science (now Case School of Technology) he was vice-president of the Tennessee Copper Co., and for three years was consultant for the Canadian Salt Manufacturing Co. of Ontario. He was 88 years old.

L. J. HARLOW

Laurence J. Harlow, associated with the H. K. Ferguson Co., Cleveland, Ohio, died late in 1952. A graduate of the University of Maine, Mr. Harlow first was employed by the Du Pont Co. as a control chemist, later becoming foreman, nitrocellulose production. After a year with Chemical Warfare Service, he went with Monsanto, and in 1947 joined the staff of the Ferguson company as chemical engineer in layout and design in plant construction.



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INDEX OF ADVERTISERS

Page

A

Abbe, Inc., Paul O. 55
Adams Co., Inc., R. P. 62
Aldrich Pump Co. 10
Artisan Metal Products, Inc. 58
Autoclave Engineers, Inc. 64

B

Babcock & Wilcox Co., Tubular Products Div. 15
Badger Manufacturing Co. 46
Baker Perkins, Inc. 48
Bartlett & Snow Co., The C. O. 41
Binks Manufacturing Co. 42
Burling Instrument Co. 62

C

Carbide & Carbon Chemicals Co., A Division of Union Carbide and Carbon Corp., *Inside Front Cover*
Central Scientific Co. 40
Chemical Corporation 53
Condenser Service & Engineering Co., Inc. . 42
Corning Glass Works 32, 33
Crane Company 4
Croll-Reynolds Co., Inc. 69

D

Dollinger Corporation 47
Dow Chemical Co. 6
Downingtown Iron Works 68
Duraloy Co. 44

E

Eimco Corporation 13

F

Falls Industries, Inc. 57
Filtration Engineers, Inc. 60
Fischer & Porter Co. 51
Fluor Corp., Ltd. 34

G

General American Transportation Corp. 112
General Industrial Development Corp. 5, 22
Girdler Corp. 11
Great Lakes Carbon Corp., Electrode Division 45
Gump Company, B. F. 3

H

Hardinge Co., Inc. 63
Haveg Corporation 50
Hilliard Corporation 26
Hills-McCanna Co. 52

I

International Nickel Co., Inc. 49

J

Johns-Manville 12

K

Knight, Maurice A. 61

L

Lawrence Pumps, Inc. 20
Ledeen Mfg. Co. 68
Little, Inc., Arthur D. 31

M

Metal Textile Corp. 63
Miller, Ray 62
Milton Roy Company ..... *Inside Back Cover*
Minneapolis-Honeywell Regulator Co. 8, 9
Mixing Equipment Co., Inc. ..... *Back Cover*

N

National Carbon Co., A Division of Union Carbide and Carbon Corp. 29
Niagara Blower Co. 54
Niagara Filter Div., American Machine & Metals, Inc. 70
Nicholson & Co., W. H. 64

O

Ohaus Scale Co. 65
Ohmart Corporation, The 56
Okadee Company 59

P

Pan American Chemicals Div., Pan American Refining Corp. 65
Pfaudler Company, The 16
Posey Iron Works, Inc. 23

R

Read Standard Corp. 30
Refinery Supply Co. 40
Rockwell Mfg. Co. 24, 25
Rohm & Haas Co. 43

S

Sandvik Steel, Inc. 39
Sharples Corp., The 14
Shriver & Co., Inc., T. 58
Sparkler Mfg. Co. 27
Spraying Systems Co. 56
Streeter-Amet Co. 68
Struthers Wells Corp. 7

U

Union Carbide and Carbon Corp., Carbide and Carbon Chemicals Co., *Inside Front Cover*
National Carbon Co. 29
United States Gasket Co. 21
U. S. Stoneware Co. 19

Y

York Co., Inc., Otto H. 67

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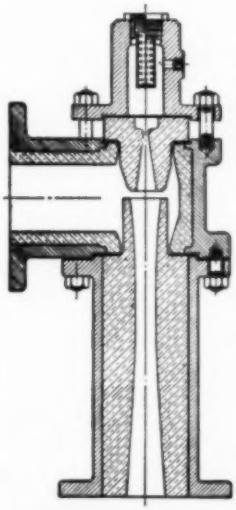

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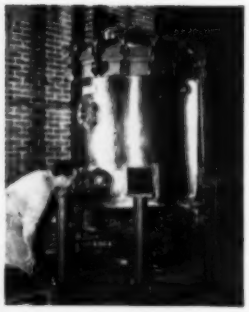

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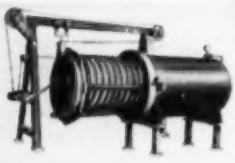
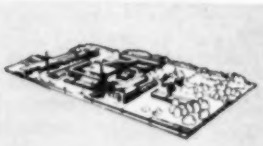


HORIZONTAL—for clarification and solids recovery.



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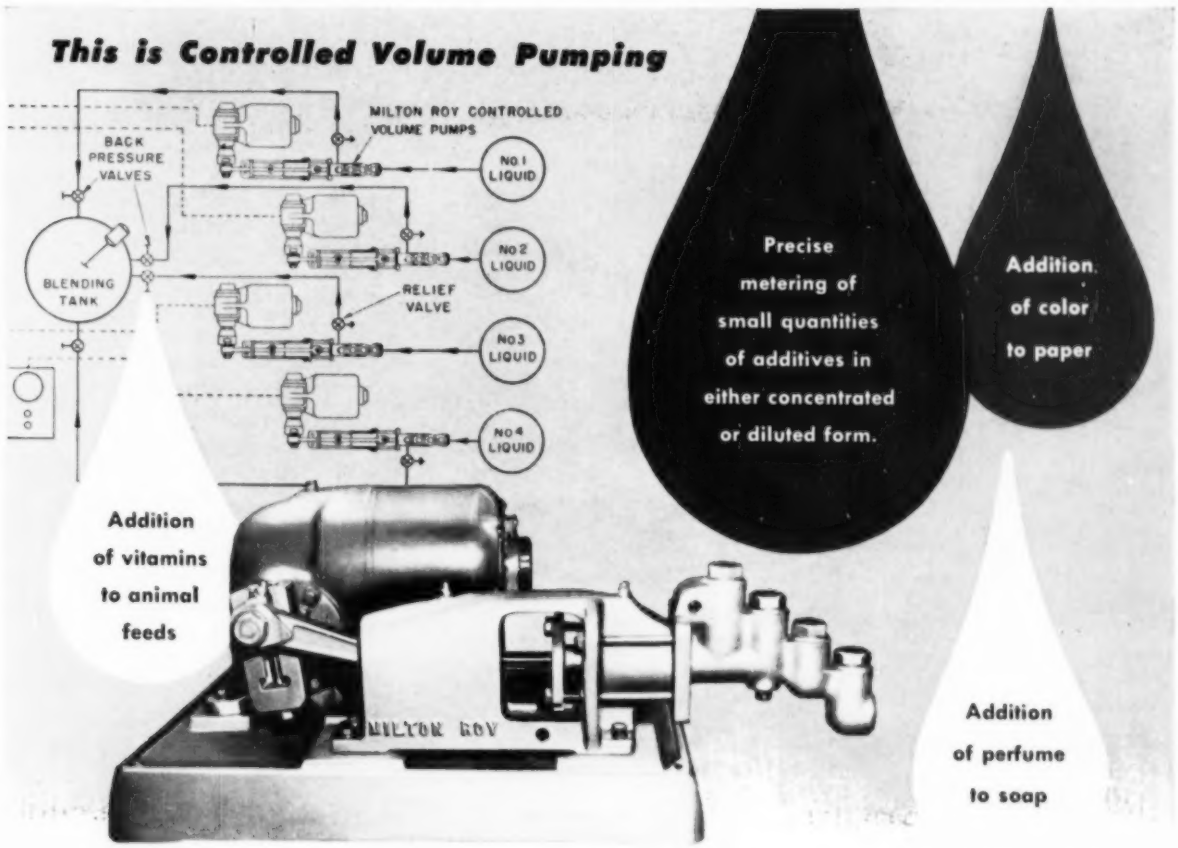

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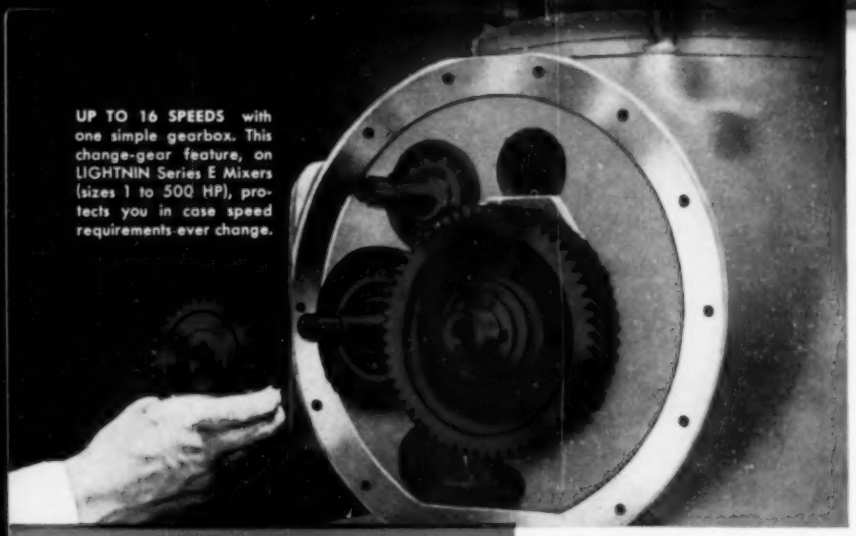

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